HELSINKI UNIVERSITY OF TECHNOLOGY
Department of Forest Products Technology

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THE SUITABILITY OF LTL FOR FURNITURE AND INTERIOR PANELS

Master's thesis for the degree of Master of Science in Technology submitted for inspection, Espoo, 15 February, 2007.

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ABSTRACT OF MASTER'S THESIS

Author
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Title of Thesis
The suitability of LTL for furniture and interior panels

Abstract

The purpose of the study was to perform the technical tests, which are required for new, conceivable Edge Glued Board (EGB) of pine for furniture and interior. The furniture and interior panels required a great number of tests, such as strength and appearance experiments. The requirement of the furniture and interior panels are different, the furniture panel required more strength properties than interior panel and the other hand the appearance of the interior panel is a great significance.

To achieve the aim; the literature part was concentrating to study already known characters of Laminated Timber Lumber (LTL) and the main competitors. The interviews were made to get knowledge, what are the demands of the furniture and interior panels and also to get opinions of the LTL. The literature part includes also a part about potential surface treatments for the LTL. The differences of the technical properties between the LTL and the competitor panels are presented in the experimental part.

The research includes 13 different experiments, 5 of them were applied experiments for the product development of the LTL. The research includes also modelling of the hardness and swelling characters of the EGB. The results imply that the technical characteristics of the LTL are good compared to the competitors' materials. The appearance of the LTL with narrows lamellas became significantly better than LTL with wider lamellas, because the finger joints became almost invisible. One of the most interesting discovery was that with porous building materials is possible to decrease ventilation, because the humidity peaks are absorbed to the building itself, therefore the energy consumption is reducing.

The experiments went technically well and those have been performed in the Laboratory of Wood Technology (TKK). While the research developed, many ideas for further studies and product development. The orderer of this research was chuffed with the achievements of the study and the further studies will start after this research.

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DIPLOMITYÖN TIIVISTELMÄ

Tekijä

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Diplomityön nimi

The suitability of LTL for furniture and interior panels

Tiivistelmä

Työn tarkoituksena oli arvioida tekniset ja arkkitehtoniset ominaisuudet uudelle mäntyliimapuulevylle, joka on tarkoitettu huonekalu- ja sisustuslevyksi. Huonekalu- ja sisustuslevyt vaativat useita eri testejä, kuten esimerkiksi lujuus- ja ulkoasutestejä. Vaatimukset huonekalu- ja sisustuslevylle ovat erilaiset, huonekalulevyt tarvitsevat enemmän lujuusominaisuuksia kuin sisustuslevyt ja toisaalta sisustuslevyjen ulkonäkö on hyvin merkittävä.

Jotta tavoite saavutettaisiin, kirjallisuusosa käsittelee jo tunnettuja ominaisuuksia LTL:stä (Laminated Timber Lumber) ja sen pääkilpailijoista. Haastatteluja tehtiin, jotta saataisiin tietoa huonekalu- ja sisustuslevyjen vaatimuksista, sekä mielipiteitä LTL:stä. Kirjallisuusosa sisältää myös pintakäsittelymahdollisuuksista LTL:lle. Kokeellisessa osassa esitetään LTL:n ja sen kilpailijoiden tekniset eroavuudet.

Tämä tutkimus sisältää 13 erilaista testiä, 5 niistä oli soveltavia testejä LTL:n tuotekehitystä varten. Tutkimus sisältää myös kovuus- ja turpoamamallinnusta. Tulosten perusteella LTL:n tekniset ominaisuudet ovat hyviä, kun vertaillaan niitä kilpailijoiden tuotteiden kesken. LTL:n ulkonäkö tuli kapeammalla lamellilla merkittävästi paremmaksi, koska sormijatkokset hävisivät näkyvistä lähes täysin. Eräs mielenkiintoisimmista havainnoista oli, että käyttäessä huokoisia rakennusmateriaaleja on mahdollista vähentää ilmanvaihtoa, koska ilmankosteus huippuarvot absorboituvat rakennukseen ja täten energian kulutus laskee.

Kokeet menivät teknisesti hyvin ja ne suoritettiin Puutekniikan Laboratoriossa (TKK). Tutkimuksen aikana kehittyi monia ideoita jatkotutkimuksia ja tuotekehitystä varten. Tutkimuksen teettäjä oli tyytyväinen työn saavutuksiin ja tuotteen jatkotutkimukset alkavat tämän tutkimuksen jälkeen.

Työn valvoja Matti Kairi, Professori	Työn ohjaaja Janne Manninen, DI Pertti Viitaniemi, TkT
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PREFACE

This research was ordered by Stora Enso Timber. The research was conducted by a steering group. The chairman of the steering group was Jouko Silèn (SET) and the other members were Pertti Viitaniemi (TKK, Wood Technology), Pekka Heikkinen (TKK, Department of Architecture), Jaakko Keronen (Puumerkki), and Janne Manninen (TKK, Wood Technology).

The supervisor of the thesis was Professor Matti Kairi. Both Janne Manninen and Pertti Viitaniemi were the instructors of the thesis. I would like to thank all the members of the steering group. Especial thanks to Janne Manninen for help in all problems during the research.

I would like to thank my Swiss base and its members, where I had opportunity to write the thesis and where I was interviewing for the thesis. Thanks also for my Italian friends for help with the interviews in Italy.

Special thanks to all members of the Wood Laboratory for all help what I got during studies and the research.

Espoo, February 2007

Lauri Rautkari

TABLE OF CONTENTS

ABBREVIATIONS

EGB	Edge Glued Board
EMC	Equilibrium Moisture Content
LTL	Laminated Timber Lumber
MC	Moisture Content
MDF	Medium Density Fibreboard
MOE	Modulus of Elasticity
MUF	Melamine Urea Formaldehyde
OSB	Oriented Strand Board
PF	Phenol Formaldehyde
PMDI	Polymeric Methylene Di-Isocyanate
PVAc	Polyvinyl Acetate
PU	Polyurethane
RH	Relative Humidity
SD	Standard Deviation
SFS	Finnish Standards Association
TEKES	Finnish Funding Agency for Technology and Innovation
TKK	Helsinki University of Technology
UF	Urea Formaldehyde
VAT	Value Added Tax

1 INTRODUCTION

1.1 Background

Stora Enso Timber has started to consider a more profitable use for the sap wood of the pine (*Pinus sylvestris* L.). The sap wood of the pine is a high-quality wood material because of its properties: high density, high strength, good impregnation, regular grain structure, and longer knot intervals in sideboards than in centerpieces.

The prices of low quality sideboards have in recent years been at a low level because of oversupply. Medium Density Fiberboard (MDF) has captured the market share of pine sideboards in many traditional sideboard end uses, such as mouldings.

This study focuses mainly on the technical suitability of the new glue lam product Laminated Timber Lumber (LTL), as well as the architectural suitability of the LTL for furniture and interior panelling.

1.2 The Aim of the Study

The main aim of the study is to clarify the technical properties of the LTL in order that Stora Enso Timber could manufacture it, as a new product for furniture and/or interior panelling. The M.Sc thesis falls into two parts. First to determine the suitability of LTL, the literature part concentrates on studying the known characters of LTL and its competitors. At the same time, interviews are conducted to determine the requirement for the furniture and interior panelling. The experimental part concentrates on the technical differences between LTL and the competitor panels. It is possible to detect the solution to the research problem, with the literature and experimental part.

1.3 The Definition of the Study

The thesis concentrates on experiments which are requisites for furniture and interior panelling. This thesis does not concentrate on manufacturing LTL either on the economic point of views.

Only the transparent surface treatment will be tested on LTL to keep the visual appearance of the product. Only porous surface treatments were chosen for the tests. A good moisture buffer value was wanted in the product.

The competitor panels were chosen by the steering group and were obtained from Puumerkki. The panels were chosen for furniture and interiors. In the table 1 the competitor panels are shown for both.

Table 1. Competitor panels.

Furniture panels Product name	Interior panels Product name
EGB pine	OSB
EGB beech	MDF panel
EGB birch	Particle board panel
Particle board	Birch plywood
MDF	

2 REFERENCES TO LITERATURE

2.1 Description of Manufacturing LTL

LTL is made of glued laminated timber; it is a high-quality, visual product for non-structural use. Glued laminated timber is made of lamellas which are glued together parallel to the grains.

LTL is made of sideboards of pine. The first step is to control the qualities of the sideboards. The knots are cut away and the pieces finger-jointed. The finger-jointed lamellas are planed and glued together. The glued laminated timber is sliced with a band-saw thus developing a radial surface. The manufacturing process of the LTL is presented in figure 1. A sample of the LTL cross section is presented in figure 2, the surface of the LTL is presented in figure 3.

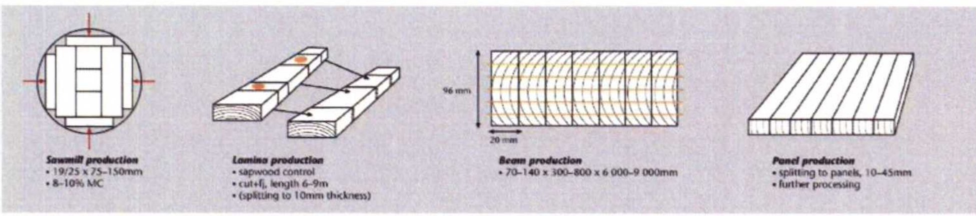

Figure 1. Manufacturing LTL. (SET, 2006)

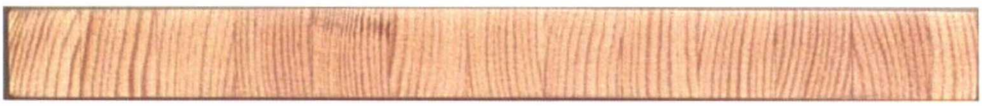

Figure 2. LTL profile.

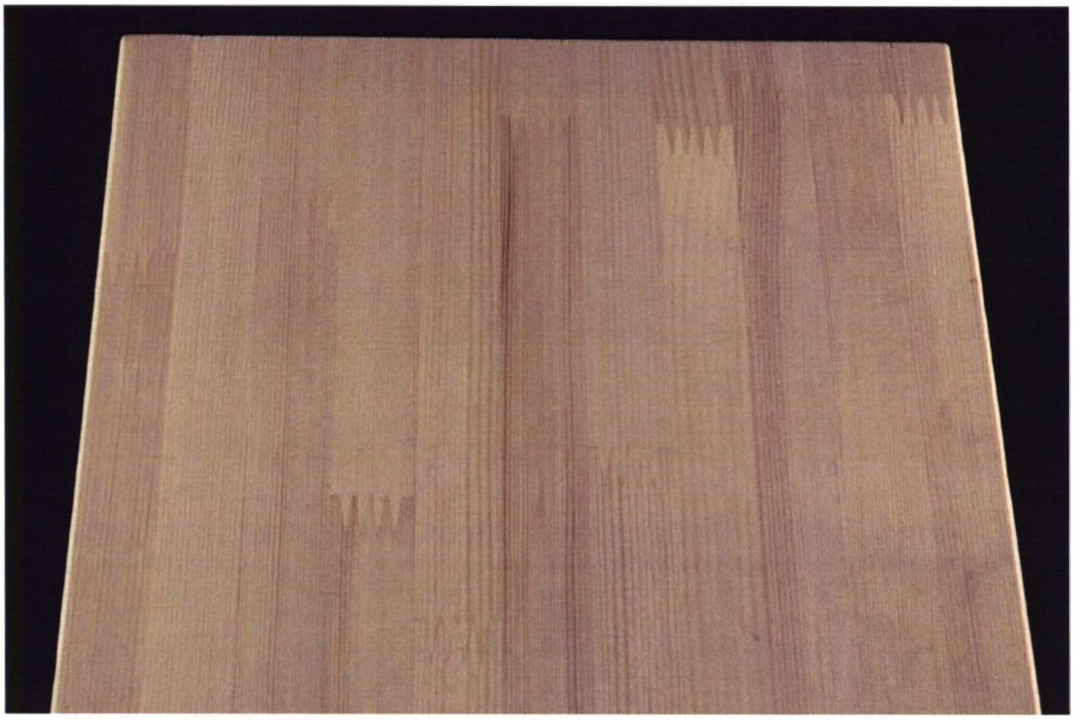

Figure 3. The surface of LTL. (Heikkinen, 2005)

2.2 The Wood Material

2.2.1 The Wood Material of Pine

The whitish outer shell of the coniferous stem wood is called the sapwood. The innermost part of the tree is called heartwood. It is normally darker, because it is dryer than sapwood. The heartwood consists of dead cells, which are the storages of different compounds. The heartwood of the pine has a great number of resin acids and phenol acids. These extractive agents protect heartwood against rot, but at the same time the appearance of problems is possible. One example is problems with the surface treatments; the resin can penetrate through the paint or lacquer layer. (Fagerstedt et al., 2005)

The properties of the sapwood and heartwood are often really different. It is difficult to differentiate the sapwood and heartwood in the fresh pine log, although the heartwood transforms darker in consequence of the light and air. As well, the growing characteristics differ between the colour of the sapwood and heartwood. Pine from Lapland, has darker heartwood than pine from Southern Finland. (Fagerstedt et al., 2005) There is a zone between the sapwood and heartwood which is difficult to impregnate like the heartwood, nevertheless it still rots easily like the sapwood (Kärkkäinen, 2003).

The pine grows commonly in the Northern and Southern coniferous forest zones of the earth. The advantages of the wood material of the pine are: the processing properties, it is easy to dry, and it has good gluing features. The differences between sapwood and heartwood could present a problem in joints. The sapwood of the pine is prone to fungi, insects, and it is not weatherproof. (Koponen, 1989)

2.2.2 Theory of the Commitment of Moisture to Wood Material

Wood is a hygroscopic material thus it can absorb humidity from the air and can keep the balance between the steam of the air and its own moisture content. Inside the cell walls there is bound water which is also called hygroscopic water and it mainly binds to cellulose and hemicellulose and also the hydroxyl group of the lignin. (Lemetteinen et al. 1987b) Each temperature and relative humidity contains its own Equilibrium Moisture Content (EMC) for each wood material. The EMC means that the incoming and outgoing moisture is equal. (Kärkkäinen, 2003)

The Equilibrium Moisture Content (EMC) of the wood material (hygroscopic balance) is different if the moisture is absorbing or desorbing to the wood. The hygroscopic balance is higher if the moisture is desorbing, and therefore when the moisture is absorbing the hygroscopic balance is lower. This event is called hysteresis. The increasing of the moisture to the wood is called adsorption and the other hand, when the moisture is decreasing, the events name is desorption. (Kärkkäinen, 2003)

2.2.3 The Convection of Water in Wood Material

Most coniferous tree cells are trakeids (90 – 95 %), water cells, which are cigar-shaped, normally called fibres. The trakeids of the early wood are composed of thin cell walls and big lumens. The cross-sections of the trakeids are square or hexagon shaped. The head of the trakeids are wedge shaped and imprecated when the contact surface for water convection is well organized. The trakeids of the late wood have thick cell walls, and the lumens are narrow. Cross-sections of the late wood trakeids are normally orthogonally shaped. The latewood trakeids are slightly longer than the early wood trakeids. (Lemetteinen et al. 1987a) The latewood and early wood trakeids and its bordered pits are presented in figure 3.

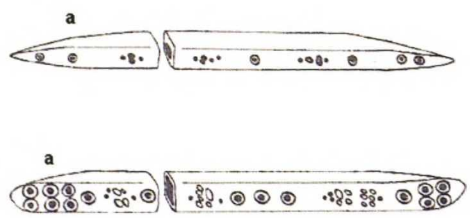

Figure 4. The latewood trakeid (upper) and early wood trakeid (lower), a = bordered pits. (Lemetteinen et al. 1987a)

Water flows in coniferous trees along cell lumens of the trakeids. It can flow to the tangential direction or along the stem from one cell to another, because there are many bordered pits. There are about 100 bordered pits between two early wood cells, and between two late wood cells about 10 - 50 bordered pits. For example, between two bordered pits of the pine, there is a valve which opens and closes the bordered pits. The valve is called the torus. Normally, the bordered pits are open, but when the wood material changes to heart wood or the wood material dries, the torus closes the bordered pits. The convection of the water in the wood material decreases. This event is called aspiration. (Lemetteinen et al. 1987a) The aspiration is basically reversible at least in the sap wood, but so weak that in practice the aspiration becomes permanent. (Kärkkäinen, 2003) Normally, when drying the wood material of the pine, all bordered pits of the early wood aspirates, but the aspiration happens only in 50 % of the bordered pits of the latewood. At the same time, bordered pits of the latewood of the spruce, aspirates more, 75 - 80 %. The bordered pits of the pine have nodules, therefore the pine does not aspirate completely. That is why it is easy to impregnate the sap wood of the pine. The spruce wood material aspirates more perfectly because of the absence of the nodules. (Lemetteinen et al. 1987a) The different type of sections of the coniferous tree is shown in figure 4. It is evident that the radial surface has more bordered pits on it than the tangential surface has.

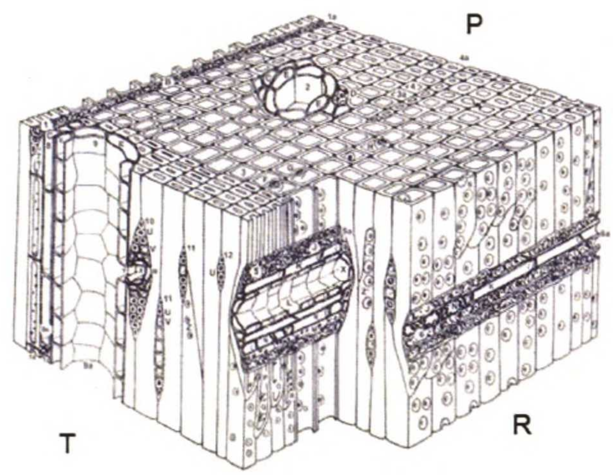

Figure 5. Section of the coniferous tree, T = tangential section, R = radial section, and P = section of parallel to the grain. (Kärkkäinen, 2003)

2.2.4 Anisotropy of the Shrinking and Swelling of the Wood Material

A piece of wood is shrinking and swelling in an anisotropic way, when the moisture is changing. Normally the swelling is differentiated to the radial, tangential and to parallel direction to the grains. In a normal tree the shrinking of the parallel to the grain, from a fresh tree to absolute dry, is 0.1 - 0.3 %, depending of the wood species. Shrinking of the radial direction is about 3 - 6 % and tangential shrinking 6 – 12 %.

Therefore the magnitude of the shrinking and swelling of the wood is really different. Density of the wood has an influence to the shrinking and swelling. Normally when the density is growing, also the shrinking and swelling are growing to the radial and the tangential directions. (Kärkkäinen, 2003) In table 2 is shown shrinking-% of different wood species. The shrinking of the pine in South-Eastern Finland is 4.0 % in radial direction and in tangential direction 7.6 % from a fresh log to a dry one (Grekin, 2006).

Table 2. Properties of different wood species. (Koponen, 1989)

	Birch	Spruce	Pine	Beech
Density, kg/m³	610	430	490	680
Shrinking, parallel to the grains, %	0,6	0,3	0,4	0,3
Shrinking, radial, %	5,3	3,6	4,0	5,8
Shrinking, tangential, %	7,8	7,8	7,7	11,8
Bending strength, Mpa	144	76	98	121
Brinell hardness, Mpa	2,5	1,2	1,9	3,4

2.2.5 Differences of Tangential and Radial Surface of the Wood

The LTL product has a radial surface, when normal EGB has mixed radial, tangential, and diagonal surfaces. In the market there are no wooden panels, which have radial surface, so there is no products where to compare LTL exactly. Same kind of radial surface is still in quarter sawn lumber, which has a little bit same kind of properties than LTL. That is why here is presented the radial and tangential ways to saw the wood.

Lumber can be cut from a log in two distinct ways: tangential to the annual rings, and radial from the pith or parallel to the radius. Quarter sawn lumber is not usually cut strictly parallel with the rays. In plain sawn boards, the surfaces next to the edges are often far from tangential to the rings. The lumber with rings at angles of 45 degrees to 90 degrees to the wide surface is called quarter sawn, and lumber with rings at angles of 0 degree to 45 degrees to the wide surface is called plain sawn. Each type has certain advantages that can be important for a particular use. (FPL, 2001) The quarter sawn lumber and plain sawn lumber are presented in figure 6.

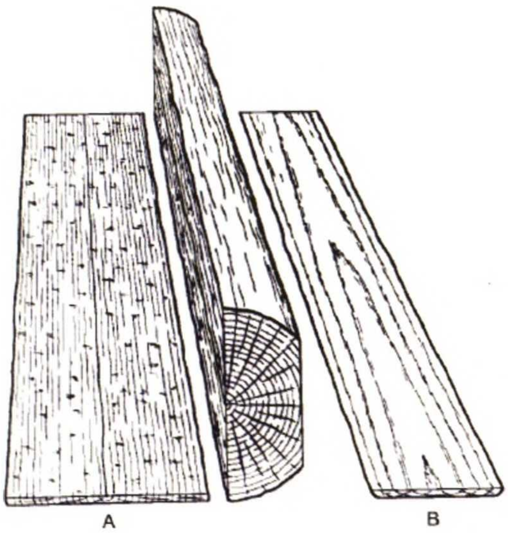

Figure 6. Quarter sawn lumber (A) and plain sawn lumber. (B) (FPL, 2001)

The Advantages of Quarter Sawn Wood:

- Shrinks and swells less in width
- Cups, surface-checks, and splits less in seasoning and in use
- Raised grain caused by separation in annual rings does not become as pronounced
- Figure patterns resulting from pronounced rays, interlocked and wavy grain are brought out more conspicuously
- Holds paint better in some species. (FPL, 2001)
- It is more resistant to wear because the dense summer bands are very close together (Armstrong, 2006).

2.3 The Main Competitors Panel Material Characters

2.3.1 Edge-Glued-Board

Edge-Glued-Board (EGB) is similar to a normal sawn board, but the plate is made of sliced timber. After slicing, slices are glued and pressed together, so that it makes a plate. Before gluing, the timber slices are turned; every second timber slice, grains up and every second down. Then the plate will be more stable than as wide sawn board. After gluing the plate will be planed to straight. It is use for furniture and joinery industry. In figure 7 is shown the method of doing EGB. (Koponen, 1989)

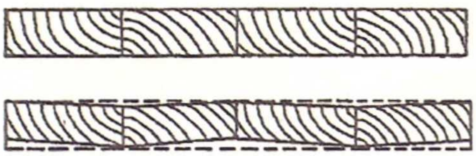

Figure 7. Profile of the EGB. (Koponen, 1989)

2.3.2 Plywood

Plywood is made from thin peeled veneers, which are glued together in a perpendicular direction. The plies are bonded under heat and pressure with strong adhesives, usually phenol formaldehyde resin, making plywood a type of composite material. A common reason for using plywood instead of plain wood is its resistance to shrinkage, twist and warping. Plywood is made of spruce or birch in Finland, but also pine. It is used for surfacing interior and exterior, structural construction, and also for concrete cast moulds. (Koponen, 2002)

2.3.3 Particle Board

Particle board, also called chipboard, is manufactured from thin logs, wood chips, or even saw dust. First the raw material is chipped to right size of chips. Then the chips are mixed with glue, dusted to normally three layers and extruded pressed. In the particle board for dry interior, the used glue is urea-formaldehyde. (Ollila, 2000) Particle board is use for furniture, joinery industry, and construction industry (Koponen, 2002).

2.3.4 Medium Density Fibreboard

Medium-density fibreboard (MDF) is an engineered wood product. MDF typically has a density of 700-800 kg/m^3. Manufacturing MDF is a combination of wet processing fibreboard and particle board. Wood materials are defibrating and dusted with glue and air. (Ollila, 2000) The most common binder is urea-formaldehyde although depending on the grade and end use of the product other binders may be used, i.e. melamine urea formaldehyde, phenolic resins and polymeric methylene di-isocyanate (PMDI) (WPIF, 2004). That compound of glue and wood fibres is pressed with high pressure and temperature. MDF will be homogenous, which is an advantage to particle board. The homogenous allows cutting figures to the surface of the MDF. (Ollila, 2000)

2.3.5 Oriented Strand Board

Oriented strand board (OSB) is a combination of plywood and particle board. It is made of layering big flakes of wood (even 100 x 40 mm) in specific orientations. The flakes are in the direction of their grain. There are three layers, in the middle layer; the flakes are 90 degrees from the surface layer, like in plywood. The manufacturing reminds of manufacturing of the particle board with small changes. (Ollila, 2000) The glue is in the majority of mills, phenol formaldehyde (PF) resin, but sometimes melamine urea formaldehyde (MUF) resin or isocyanate (PMDI) resin is used (WPIF, 2004). The strength properties of the boards are between plywood and particle board, depending on the direction of the load. The swelling properties are the same as the particle board. OSB is difficult to surface with traditional methods, because the surface of the OSB is irregular. It is normally used only for construction industry. (Ollila, 2000)

2.3.6 Prices of the Competitors Material

The price is one of the competitive tools of marketing strategy. In table 3 are the most usual products of the competitors and their prices. The prices of the suppliers are calculated with hypothesis that the margin of the retailers is 25% and the VATs are 22%.

Table 3. Competitors' prices. (Nicolaou, 2006)

Material	Retailer	Thickness	Retail's price		Supplier's price		Period
		mm	€/m³	€/m²	€/m³	€/m²	
Beech worksurface (EGB)	Puukeskus	30	2688	80,6	1573	47,2	Nov-06
Oak worksurface (EGB)	Puukeskus	30	3763	112,9	2202	66,0	Nov-06
Walnut worksurface (EGB)	Puukeskus	30	5146	154,4	3010	90,3	Nov-06
Laminate worksurface	Puukeskus	30	1380	41,4	807	24,2	Nov-06
Birch EGB	Puukeskus	18	3457	62,2	2022	36,4	Nov-06
Pine EGB	Puukeskus	18	1222	22,0	715	12,9	Nov-06
Melamine particleboard board	Puukeskus	18	678	12,2	397	7,1	Jun-06
Birch plywood (WISA-deco)	Puukeskus	12	2375	28,5	1389	16,7	Sep-06
Painted MDF panel	Starkki	10	1150	11,5	673	6,7	Sep-06
Melamine particleboard panel	K-rauta	11	1082	11,9	633	7,0	Sep-06

2.3.7 Strength Properties of the Competitor Materials

In tables 4 and 5 are collected the bending properties of the main competitors. The strength values are characteristic strengths. These values have been collected for the comparing of the experimental part.

Table 4. Strength properties of the furniture panels.

	Test method	MDF	Particle-board
Thickness, mm		12-19	13-20
Density, kg/m³	EN 323	400-600	700
Bending strength, N/mm², major axis	EN 310	≥31	13
Bending strength, N/mm², minor axis	EN 310	≥31	13
Modulus of elasticity, N/mm², major axis	EN 310	≥2700	1600
Modulus of elasticity, N/mm², minor axis	EN 310	≥2700	1600
References		Egger	Puhos Board

Table 5. Strength properties of the interior panels, (*= test has done in mc 7-8% and the board size was 1200mm * 1200mm).

	Test method	Birch plywood	MDF	Particle board	OSB
Thickness, mm		12	9-12	6-13	6-10
Density, kg/m³	EN 323	690	400-600	700	≥590
Bending strength, N/mm², major axis	EN 310	57,9	≥35	13	≥22
Bending strength, N/mm², minor axis	EN 310	43,8	≥35	13	≥11
Modulus of elasticity, N/mm², major axis	EN 310	10957*	≥2800	1800	≥3500
Modulus of elasticity, N/mm², minor axis	EN 310	7766*	≥2800	1800	≥1400
References		Finnforest	Egger	Puhos Board	Egger

2.4 Earlier results of the LTL

Following tests were made in Wood laboratory of TKK in autumn 2005.

2.4.1 Flotation - Halogen Light Test

The flotation – halogen light tests are made to find out, how much different kind of wood samples are splitting during the test cycles. The sizes of the wood pieces were 70 * 150 mm and the edges were coated with silicon mass. The cycles started with samples floating 1 hour on water and then 1 hour under halogen light. The halogen light distance was set to achieve surface temperature 80 °C. Between each cycles the number of the splits were calculated and the sizes were approximated adapting SFS-3762 standard. There were 10 cycles. In figure 8 are shown results of 9 materials. The material names were: P-HW is heartwood of pine board, P-S is sapwood of pine board, S-HW is heartwood of spruce board, S-S is sapwood of spruce, HT is heat treated spruce board, S-LTL is LTL which is made of spruce, P-LTL zigzag is LTL which is made of pine with visible finger joints, P-LTL line is made of pine and finger joints which are as a line, and LTL-HW is LTL which is made of the heartwood of pine. The results were collected from Tiina Mehtälä's M.Sc. thesis and researches in Wood Laboratory of TKK 2006. The size and mark of the splits were multiplied and compared with other materials. The main result, which is interesting for this M.Sc. thesis, is that glued LTL is more durable than normal boards and the direction of the finger joint direction is more durable as a line than as a zigzag.

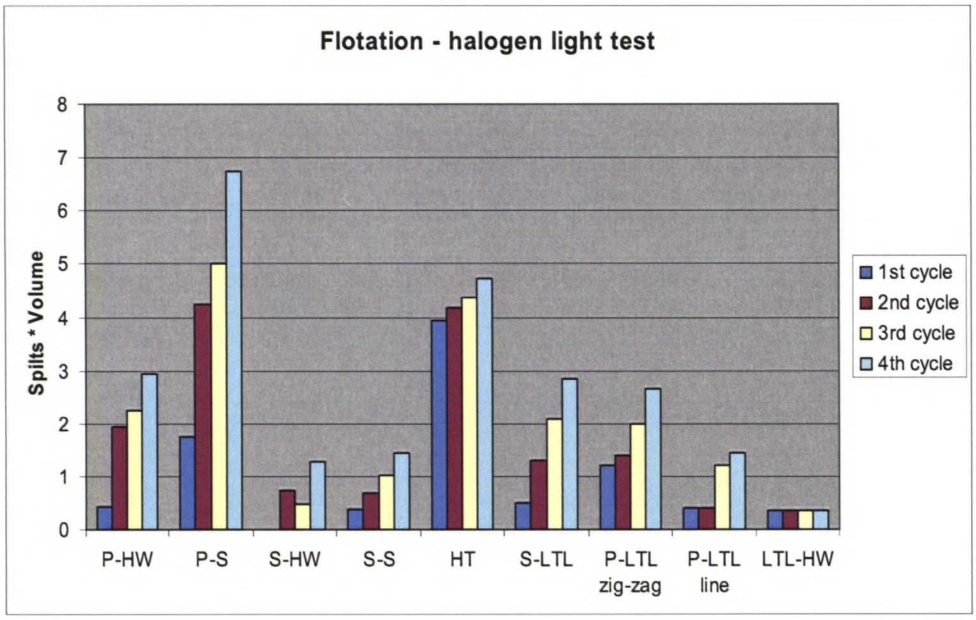

Figure 8. Flotation- halogen light test results. (Mehtälä, 2006)

2.4.2 Modulus of the Elasticity of the LTL

The modulus of the elasticity - tests were made in Wood laboratory of TKK in autumn 2005. The LTL contains heart wood and the finger joints are visible, as a zigzag. The HW LTL is heart wood of the pine and it is made with thick lamella (4 cm) and the finger joints are invisible as a line. The sound knot means regular top-log pine, as used in flooring or EGBs. The sideboards were 10-15 % stiffer and the biggest standard deviations were with sound knot timber. The tests were made according SFS-EN 408. Mean values of the modulus of elasticity are presented in figure 9.

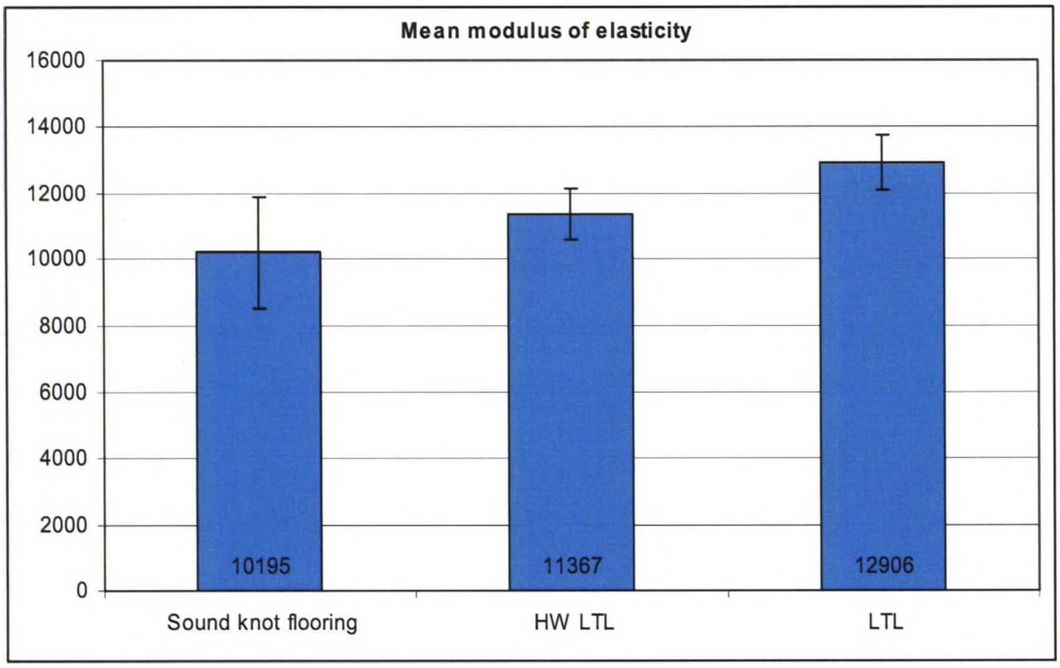

Figure 9. Mean modulus of elasticity. (Manninen, 2005)

2.4.3 Brinell Hardness of the LTL

Brinell hardness of the LTL panel was measured in autumn 2005. Larch (flatside) samples have been taken from 25 mm 4ex sawn larch from Central Europe. Birch (flatside) samples have been taken from 40 mm through sawn birch from Southern Finland. 28 mm thick centerpiece- and sideboard floorings were tested from both sides, so the 'lacquered' and 'clear' values have been got from the same pieces. Centerpiece (flatside) and sideboard (flatwise) samples had been taken from the same raw material than the centerpiece and sideboard floorings. Hardness testing was made to the tangential surface of these pieces. Testing had been done according to EN-1534. Maximum load used in testing was 0.5 kN instead of 1 kN required in the standard. (1kN was too high load for softwood species, and measurements could not be done with that load). The Brinell hardness of LTL is presented in figure 10.

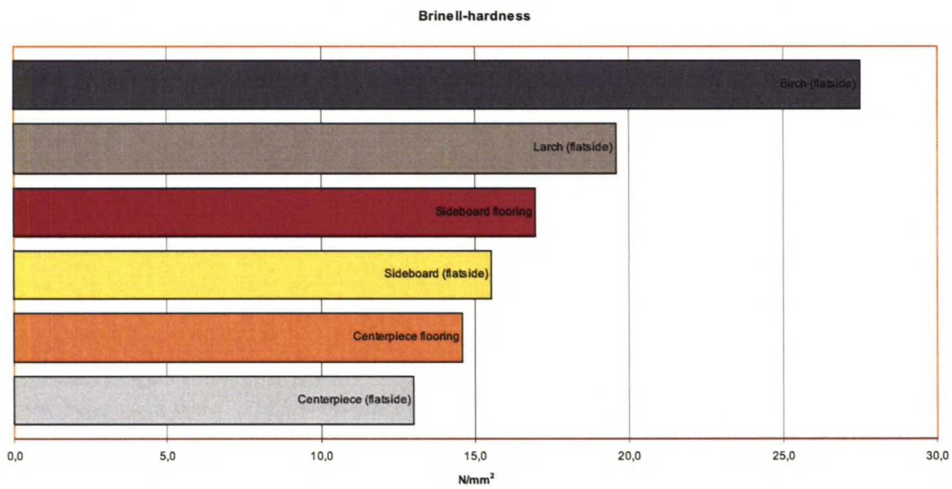

Figure 10. Brinell hardness of LTL. (Manninen, 2005)

2.4.4 Appearance of the LTL

TKK Department of Architecture has made a research project from autumn 2005 to spring 2006 for Stora Enso Timber. It was a research project about new glued laminated product LTL and its visual face. The research included different applications of LTL in different forms of LTL. The research based on interviews of architects, designers, and civil engineers. (Heikkinen et al., 2006)

With small lamella size it is possible to create a calm and serene pattern of the product. The plain joints with the grain pattern evoke strong linear appearance and it gives to the product obvious direction. Visual benefits of the small lamella come out when the close-textured plain joints are used on the visible surface. (Heikkinen et al., 2006)

The amount and quality of the knots affect strongly on the appearance and image of the product. A purely knotless product could suite for designs where the use of wood is modern and anonymous. (Heikkinen et al., 2006)

The quantity of heartwood and sapwood in visible surfaces of LTL has a great effect on the appearance of the product. The selection of the lamellas should be strict, and to have a control in the appearance of the visible surfaces. The product variety could include products that are composed of only heartwood or sapwood, or combination of both materials. The composite products should have a calm and serene appearance. This appearance can be reached if the sapwood and heartwood is mixed in the controlled way. With different colours of sapwood and heartwood it is also possible to create predefined pattern to the surface of the product, e.g. stripy surface. (Heikkinen et al., 2006)

The direction of the finger joints has an effect on the appearance of the product. The pattern of the surface is important mainly in interior use. The visible saw-edged finger joint has an innovation value and it could be considered as a decorative element. The visible straight finger joint is a safe choice that is usable in most of the cases. Visible straight fingers do not divide the customers' opinions as much as the visible sawn-edged fingers probably will do. (Heikkinen et al., 2006)

Due to the radial sawing, the visible surface of the product gets a calm appearance. The dense grain pattern of the face is attractive. This matter peaks using the lamellas shorter edges in the visible surface. (Heikkinen et al., 2006)

The most important matters having an effect on the visible surface are the knots, the size of the knots and density, the colour difference of the sapwood and heartwood and the direction of the finger joints. If one of these things emerges strongly, the appearance will be restless. The calm and sereneness of the surface requires that these matters will overrun equally in visible surfaces. The regular quality of upgraded products is important. (Heikkinen et al., 2006)

The finished and sharp appearance of the LTL as a whole is a clear advantage. The prototypes had a look that was more like a work of a carpenter than an industrial product. The product was perceived as an interesting and competitive, due to its visual properties. (Heikkinen et al., 2006)

2.5 Other Test Results

2.5.1 Hygroscopic Buffer Effect

Indoor humidity is an important parameter to determine the occupants' perception of indoor air quality, and is also an important parameter as a cause of harmful processes that may occur on surfaces of materials, such as microbial growth. Thus, it is known that humidity has an impact on both the working efficiency and health of occupants. But due to the varying loads, the indoor humidity exhibits significant daily or seasonal variation. Materials that absorb and release moisture can be used positively to reduce the extreme values of humidity levels in indoor climates. The use of building materials to moderate the thermal indoor environment has been a topic of research in hygrothermal conditions for buildings since at least the beginning of the 1980's, and the results have been used in building design and analyses since then. There is now an increasing interest in including in the analyses the moisture buffering properties of absorbent, porous building materials. (Rode, 2005)

The capacity of materials to absorb humidity or desorbs moisture to air, when the relative moisture is chancing, is called hygroscopic. The optimal indoor relative humidity (RH) level is between 28 – 55 %. (Kokko, 2002) The practical Moisture Buffer Value ($MBV_{practical}$) indicates the amount of water that is transported in or out of a material per open surface area, during a certain period of time, when it is subjected to variations in relative humidity of the surrounding air. When the moisture exchange during the period is reported per open surface area and per % RH variation, the result is the $MBV_{practical}$. (Rode, 2005)

Kokko (2002) has made a summary of researches of laboratories and practical buildings, concerned about indoor humidity. In figure 11 are theoretical results that the material, which has great practical moisture buffer value, will steady the humidity fluctuation. The wall materials were wood based porous materials. The consideration target is a typical size bedroom, which has accordance with regulations ventilation (half of the air of the room changing each hour). Two adult occupants are sleeping during 23.00 – 07.00, the hypothesis is that they produce steam 60 g/h.

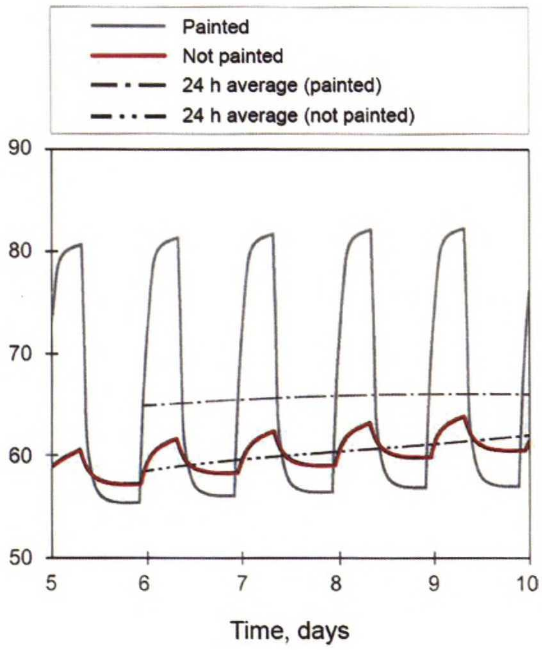

Figure 11. Rooms RH-% differences between painted and not painted wall. (kokko, 2002)

2.6 General Coating Material and Methods

2.6.1 Veneer Facing

The veneer is thin panel-like made of turned or sliced log. Normally the thickness of the used veneers is about 0.4 – 0.6 mm. Veneer facing means that wooden veneers are glued on the board surface. Normally the boards are particle boards or MDF. The veneers are made of high quality and valuable wood material as oak, beech, walnut, cherry tree, or birch. Commonly the veneer trees are selected already in the forest. Also some rootstocks are used for veneers, to get curly figured veneers. (Puuproffa, 2006)

In veneer facing they use urea formaldehyde resin glue (UF) or polyvinyl acetate glue (PVAc) to glue the veneer on the board. UF glue cures quickly chemically, when heated. It is used in industry, because it is cheap and it needs short pressing time. Glue line emits formaldehyde. PVAc glue is dispersion-type glue, which is the most used glue for joinery and carpenter industry. The glue solidifies when the water vaporizes away or absorbs to wood. (Puuproffa, 2006)

2.6.2 Oiling

Hot pressed linseed oil is used with turpentine for wood surface treatment. Wood oils have a best quality resistant to wear and to moisture, if compared between natural oils. One of the most successful wood oil is Chinese wood oil, "tung oil". Oiling as a treatment needs a careful finishing, because the oil does not hide anything under it. In finish grinding should use at least sandpaper of 240 grades. The oil is used as much as the wood material can absorb. After 10 – 15 minutes of the absorption, the rest of the oil is needed to dry. Oil surface treatment is made again next day. The oil is adsorbed differently, in different wood species and different wood directions. The drying times are for hand treatments. (Auvinen et al. 2002)

2.6.3 Waxing

The waxes are based on beeswax. Only the beeswax as such is not enough. To give good quality many producers have begun to blend waxes together. The carnauba wax is made of excretion of the Brazilian carnauba palm tree and it is known for a long time. Normally producers blend beeswax and carnauba wax, to get good quality wax. (Auvinen et al. 2002)

The wax does not absorb as well than the oils. It penetrates only to the pores of the surface and creates a layer on the surface. That is why it is recommended to first prime the surface with oil and then use wax. Deeply penetrated oil guarantees that moisture and dirt can not come inside to the wood, if the wax surface has wore or there are scratches or dents. Wax spreading is doing same way than oiling. First spreading as much wax as the wood material can absorb and then unnecessary wax is taken out from the surface. After 6 - 12 hours of the waxing, the surface can be polished or waxed again. The drying times are for hand treatments. (Auvinen et al. 2002)

It is found that wax surface needs actually oil treatment under it, so some producers have developed products which have oil and wax compounds. Thus with only spreading, it is possible to get wax surface and a deeply penetrated oil treatment. (Auvinen et al. 2002)

2.6.4 Staining

The stain dries fast and drying is also possible at a higher temperature. Because of the low surface tension of the stains, the stain treatment will be fine and regular, in most of the wood species. It is seldom that stains are used only themselves, normally with 1 - 2 lacquer surfaces. (Grannefelt & Flink, 1996)

2.6.5 Lacquering

Catalyse lacquers are normally used in furniture and joinery industry. They make wear and chemical resistant surface and they are filling well the surface. Polyurethane lacquers are based on 2 compounds. Those lacquers make elastic and resistant surface to wear, but drying time is longer than with catalyse lacquers. UV lacquers are drying with UV light and that is why the lacquer surface is drying really fast, only in 5-15 seconds. Water based lacquers have many advantages, e.g. industrial safetyness and ecological matters. There are also disadvantages; swelling problems of the wood material and the lacquering surface dries rather slowly. (Grannefelt & Flink, 1996)

It is natural that the coniferous wood material becomes yellow, because of the UV light of the sun. This event is not possible to totally avoid even with UV-filter lacquers. First it must be sure that the lacquer and the wood species suit together, because sometimes lacquer and wood material make chemical reaction and colour troubles. (Grannefelt & Flink, 1996)

2.6.6 Lye treatment

Nowadays it has come in fashion to use lye treatment in solid wood furniture. The process liquid is rather strong and it is for patinate the wood surface to make it look like older. After lye treatment, it is good to use grease based treatment also. Normally the lye treatment products are based on soap. (Heikkinen, 2000)

2.7 Properties of the Surface Treatments

The Finnish Funding Agency for Technology and Innovation (TEKES) financed in 1994 comprehensive research project of ecologic surface treatments. It was found that the biggest problem with ecologic treatments is long drying time. Polymerize of the plant based oils takes at least 12 hours to dry.

Denmark has the same markets than Finland and uses a lot of Finnish pine. Their ecologic surface treatments are oiled, natural and lye treatment. Lay treatment is very popular with the massive pine furniture.

They did tests of resistance to water, alcohol and coffee for pine and birch material. The test was made according to ISO-4211-1979 and it was a visual test. The test materials were birch and pine and the sizes were 125 x 400 mm. Surface treatment methods were brush, spray, and sponge. There were a number of different ecologic surface treatments in the tests.

There was so many variations (methods and materials) that they could not put the treatments in order of superiority. The main results were that all ecologic surface treatments give much better results with the pine than with the birch. One reason is that the wood material of the birch is lighter than pine and so all dirtiness are easier to see on it.

The surfaces of the furniture panels are tested in Finland with standard methods. There are some small differences for example in Finnish and Swedish methods, mostly with the time of the tests. Finland exports quite much furniture to Sweden, so that is why they use quite much of Swedish Möbelinsitut methods for the testing of the furniture surfaces.

In the Swedish Möbelfakta, they test following tests:

- Resistance of the water, alcohol, coffee, and acetone,
- Scratching test,
- Resistance of the grease,
- Resistance of the heat,
- Resistance of the impact.

(Grannefelt & Flink, 1996)

3 DESCRIPTION OF THE EXPERIMENTS

3.1 The Interviews

In the beginning of this research project, the steering group decided to make interviews of the LTL, before technical tests. The aim of the interviews was to get knowledge, what are the demands of the furniture and interior panels and also to get comments of the LTL, technically and visually.

The interviews were made in Finland, Switzerland and Italy. Those countries were chosen, because the writer of the thesis had the opportunity to live in Switzerland during the summer 2006. The steering group was also interested in getting the knowledge from the Central Europe.

The interviews were made for architects, carpenters, and the others which had knowledge of wood material. The interviews were made more like conversations, because then the persons who were interviewed could give more informative answers than with the questionnaire interview. The interviewer presented also the LTL samples in different thicknesses (4, 10 and 25 mm) and with different surface treatments e.g. oiled and waxed. The main questions are in appendix 1, but the questions changed a little bit each time, depending who was interviewed. The interviewed persons are presented in table 6.

Table 6. Interviewed persons.

	Name	Organization	Status
1	Buri, Hani	EPFL, Laboratory for Timber Construction	Architect
2	Craviolo, Pietro	Palumbo Legnami	Co-manager
3	Fischer, Jürg	Hochschule für technik	Dipl. Civil Engineer, Lecturer
4	Lylykangas, Kimmo	Arkkitehtuuritoimisto Kimmo Lylykangas	Architect
5	Patella, Walter	Politecnico di Torino	Architect, Carpentier
6	Pichelin, Frédéric	Berner Fachhochschule	Dr Ing. Wood Sciences
7	Rantala, Tapani	Puusepänliike E. Rantala Oy	Manager
8	Schroderus, Aimo	Idea-Puu Oy	Manager
9	Scoglio, Paolo	Denaldi Legnami	Architect
10	Verleyen, Tristan	W&K	Architect student
11	Virtanen, Kari	Nikari Oy	Carpenter
12	Vuichard, Eric	Menuiserie Charpente, Vuichard J.	Co-direkteur
13	Zein, Tanya	L-ARCHITECTES	Architect

3.2 The Wood material

The LTL wood material came to Wood laboratory of Helsinki University of Technology in spring 2006. Its origin was South-Eastern Finland. It was band sawn to 5 different thicknesses 14, 16, 26, 32, and 44 mm. The wood material moisture content was about 14 %. First practical work was piling the wood material to moisture chamber of RH 65 %, it was made on 15.06.2006. LTL billets were piled, in the bottom the thinnest ones and on the top the thickest ones, because the hypothesis was that the thinnest LTL will twist and cup mostly. The competitor wood materials were put later on 15.6.2006 to the same RH 65 % chamber and their moisture contents were not measured, but hypothesis was that their moisture contents were 8-12 %. That time there was no decision which kinds of tests would be made, which is the reason why the chamber was filled more than maybe needed. The wood materials were numbered, the list is in appendix 2 and the photos of the wood material are in appendix 3.

3.3 Measuring Instruments

The calliper rules were Mitutoyo “DIGIMATIC” callipers. In table 6 are information of the callipers.

Table 7. Information of the Mitutoyo callipers.

Model	Range (mm)	Resolution (mm)	Accuracy (mm)
500-161U	0 - 150	0,01	±0,02
500-500-10	0 - 450	0,01	±0,05

The scales were Sartorius’ brand. In table 7 are information of the scales.

Table 8. Information of the Sartorius scales.

Model	Range (g)	Resolution (g)	Accuracy (g)
BP 3100 S	0 - 3100	0,01	±0,01
IC 64	0 - 64000	1	±0,5

The dial indicators were Mitutoyo “DIGIMATIC” dial indicators. In table 8 are information of the dial indicators.

Table 9. Information of the Mitutoyo dials indicators.

Model	Range (mm)	Resolution (mm)	Accuracy (mm)
543-681 B	12,7	0,01	±0,02
575-113	25	0,01	±0,02
543-464 B	50	0,01	±0,04

3.4 Tests of the surface treatments

The steering group decided to test the different surface treatments, the reason was both consider of the appearance and technical suitability for the LTL. Five different surface treatments have been done, with different colours. The surface treatments were chosen in function of their availability in ordinary do-it-yourself shop and of the ones the steering group decided to choose.

3.5 Brinell Hardness - Effect of the Grains Direction to the Brinell Hardness

3.5.1 Material

The test material was LTL. The test samples were conditioned 9 weeks in RH 65 % moisture chamber.

3.5.2 Test Specimens

The Brinell hardness tests were made according to EN 1534 standard. The sizes of the LTL samples were 25 * 18 mm and the lengths were 100 mm. The lamellas were cut separately, because then it was possible to test also the tangential hardness and also because of the possibility to measure the densities of each test samples. The numbers of the test specimens were 66.

3.5.3 Loading Arrangements

Hardness is a non-specific concept if compared with the other strength aspects. The hardness could define to wood material characteristic to resistance of solid objects, which are forced inside the wood surface. The hardness of the wood material is biggest parallel to the grain. (Kärkkäinen, 2003)

Brinell hardness for wood and flooring accords the standard EN 1534. There is a hardened steel ball, with a diameter of 10 ± 0.01 mm, which is loading to the surface of the test specimen. The standard required using 1 kN load, but 0.5 kN was used, because the wood material was too soft. The maximum load was noted and the diameters of the indentations were measured. The Brinell hardness is calculated with the formula 1. The Brinell hardness loading equipments are presented in figure 12.

$$HB = \frac{2F}{g\pi . D[D-(D^2-d^2)^{\frac{1}{2}}]}, \qquad (1)$$

where,

HB	is the Brinell hardness in kilogram force per square millimetre,
g	is the acceleration of gravity, in metres per second squared,
π	is the "pi" factor (~3,14),
F	is the nominal force, in Newtons,
D	is the diameter of the ball, in millimetres,
d	is the diameter of the residual indentation, in millimetres.

In radial surface the latewood and early wood growth were measured at the point of the indentation and latewood-% was calculated. In the tangential surface it was noted, was the indentation on latewood, early wood or in the middle of them. Also the grain angles were measured in the both surfaces. The moisture content was checked with 10 samples. The dimensions and the weights were measured for the calculations of the density.

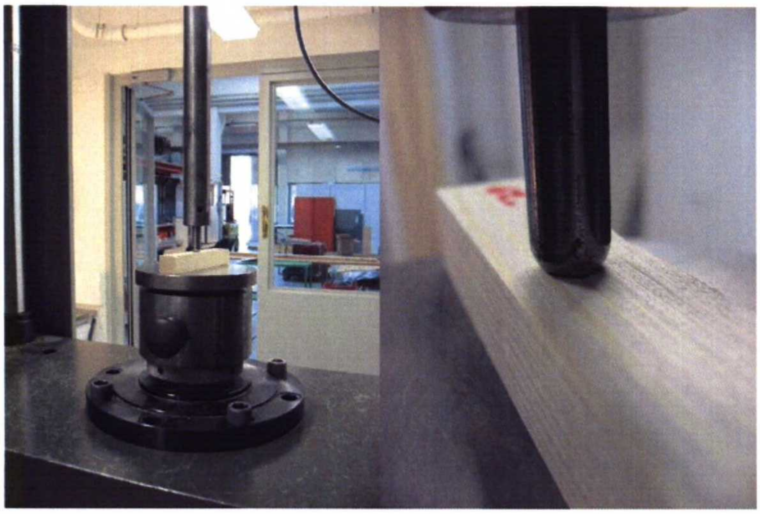

Figure 12. Brinell hardness loading equipments.

3.6 Assessment of Resistance to Impact

3.6.1 Material

The standard ISO 4211-4 specify that the specimens should be at least 7 days in RH 50 ± 5 % and 23 ± 2 °C. The samples were conditioned 2 weeks in salt chamber RH 54 % (magnesium nitrate + distilled water). The test materials were 1, 2, 4, 5, 9, 10, and 11 (presented in appendix 2)

3.6.2 Test Specimens

The resistances of the impact tests were made according to ISO 4211-4 standard. The wood materials were cut to 75 x 350 mm, not as the standard required 120 x 140 mm. Different sizes helped to produce the tests. There were 5 parallel samples of solid wood in each series and 1 sample of wood based panels. The hypothesis was that the wood based panels, such as particle board or MDF, are rather homogenous and therefore only 1 sample is needed as the standard required. The thicknesses were actual products thicknesses, and LTL thickness was 20 mm.

3.6.3 Loading Arrangements

The impact test was made with equipment, which is presented on figure 13. A cylinder steel weight 500 g (b in figure 14) was dropped from specified heights onto a steel ball of diameter 10mm, which is positioned on the test panel. The dropping heights were 10, 25, 50, 100, 200, and 400 mm. The weight was dropped 25 times to different places and different heights to each sample. The densities and moisture content were measured from each sample.

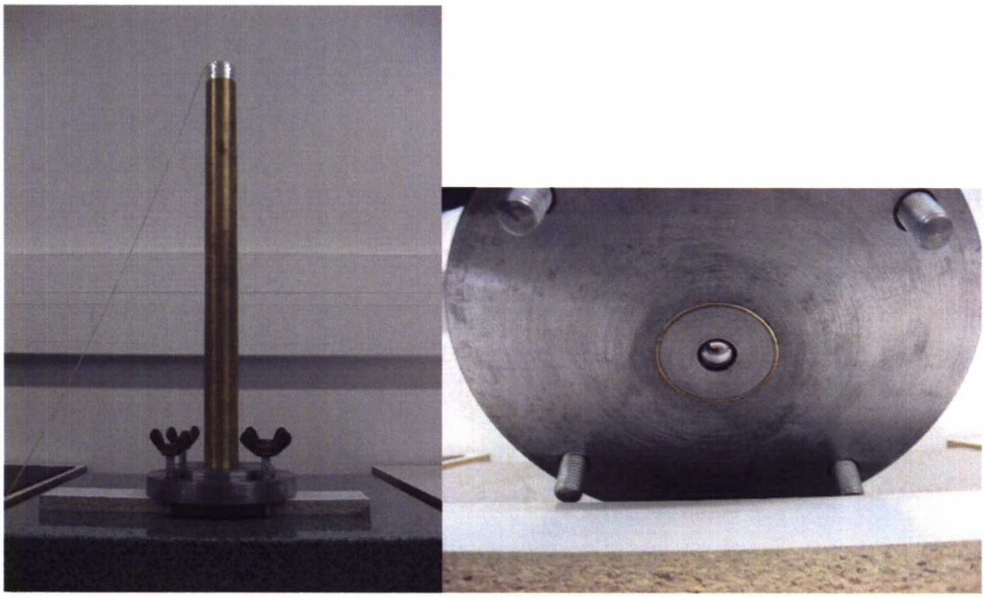

Figure 13. Impact testing equipments.

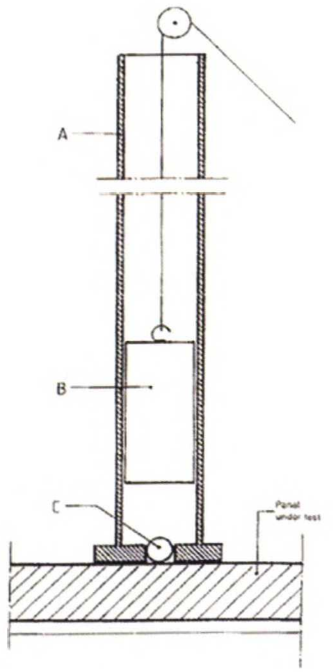

Figure 14. The test equipment according ISO-4211-4.

3.7 Screw Test

3.7.1 Material

The test material was conditioned 9 weeks in moisture chamber RH 65 %. The test materials were 1, 2, 3, 4, 5, 10, and 11 (presented in appendix 2).

3.7.2 Test Specimens

The test of resistance to hold the screws were made according to SFS-EN 320 standard. The wood materials were cut to 75 * 75 mm pieces and 3 mm holes were drilled on the middle of the surfaces. The screws (figure 15) were screwed in the same depth (20 mm) in each sample in the hole, and screw dimensions were 32 * 4.8 mm. There were 25 samples of each material. The thickness was not relevant in the test.

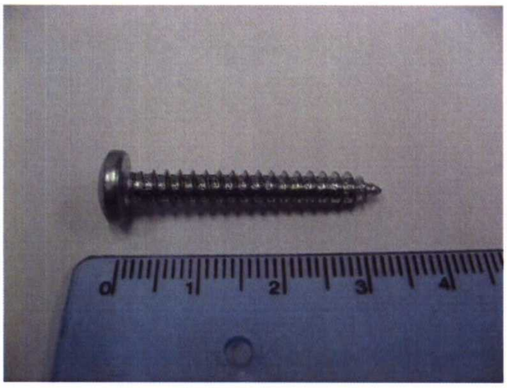

Figure 15. The used screw.

3.7.3 Loading Arrangements

Face withdrawal of screws was determined by measuring the force required to withdraw a defined screw from the test piece. The axial load rate of movement was constant 10 mm/min until the maximum load was achieved. The maximum forces f_{max} were noted. The densities and moisture content were measured from each sample. The screw test loading equipments are presented in figure 16.

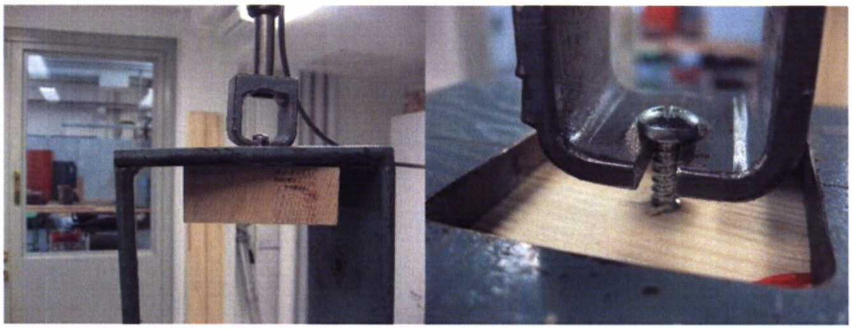

Figure 16. Screw test loading equipments.

3.8 Stability Test

3.8.1 Material

The wood materials were first conditioned in RH 65 % chamber. The test materials were 1, 2, 3, 4, 5, 6, 9, and 10 (presented in appendix 2). The panels were placed to the moisture chamber vertically, long side on the floor, so that there was no stress generated. Between each board were batten for ventilation and space for conceivable deformation.

3.8.2 Test Specimens

The width of the LTL HW samples were 220 mm and the width of the other panels were 400 mm. The lengths of the samples were 2000 mm and the thicknesses were the same as the product has, besides the LTL thicknesses were 10, 12, and 15 mm and LTL HW thicknesses were 20 and 28 mm. The number of the test specimens was 5, but the number of the OSB panels was only 3, because of the lack of material.

3.8.3 Measuring Arrangements

The stability tests were made according to SFS-EN 13647 and EN-1910 standards. The measuring table is presented in figure 17. The measuring conditions of the standard follows figure 18. While measuring, it was discovered that the moisture chamber did not follow the setting values. It made the tests complicated and slowed down the measurements rather much. The measuring conditions are presented in figure19. The duration of each conditioning period was more than 1 month.

Figure 17. The measuring table.

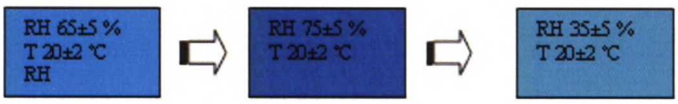

Figure 18. Required conditions in stability test.

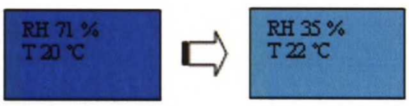

Figure 19. Measuring conditions in stability test.

After each conditioning, the samples masses were scaled and the deformations were measured. The different measurements of the deformation were twist, spring, bow, and cup. They are presented in figure 20. The twists were measured on both sides, 25 mm from the end and 15 mm from the edge of the samples. The spring was measured from the middle of the samples, on both sides. The bow was measured on both sides, but at different edges from the middle of the samples. The cupping was measured from 50 mm from the end and the middle of the samples and on both sides, thus from 6 different points of the sample. The correction coefficients for the width of the samples were calculated in hypothesis that the radius of the cupping will stay the same. In figure 21 is presented the geometry of the circular, where "s" is the length of the arc and the "R" is the radius of the circular. In the case of the cupping of the wood material "s" is the width of the sample and "h" is the measured cupping. The calculated correction coefficients was 3.31, it means that the narrower (220 mm) sample width was multiplied with 3.31 and then it is comparable with wider samples (400 mm).

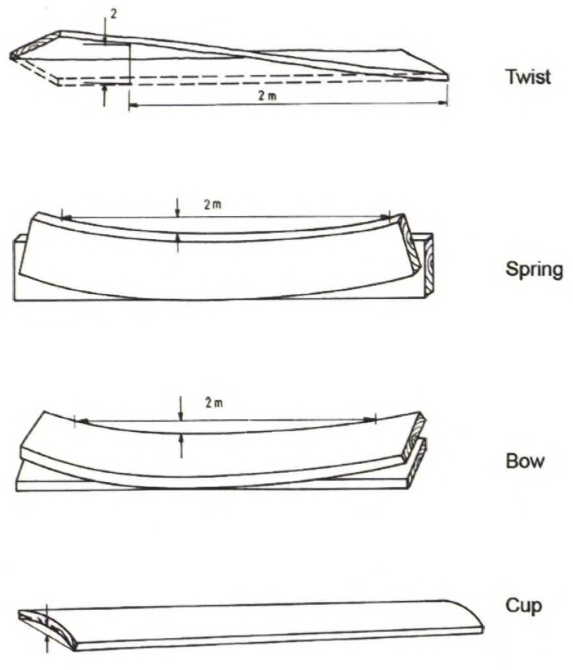

Figure 20. Measured warping types. (Esping, 1988)

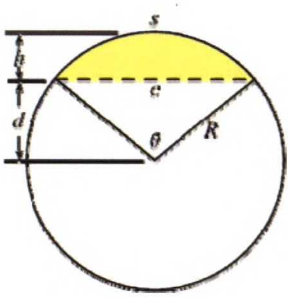

Figure 21. The figure of the geometry of the circular. (Wolfram, 2003)

3.9 Swelling Test

3.9.1 Material

The wood materials were first conditioned in RH 65 % chamber. The wood materials were 1, 2, 3, 4, 5, 7, 8, 10, and 11 (presented in appendix 2).

3.9.2 Test Specimens

The swelling tests were made according to SFS-EN 13647 and EN-1910 standards. The dimensions of the specimens were: width 400 mm, length 50 mm (parallel to the grain), and the thicknesses were the same as the product thicknesses, besides the thicknesses of the LTL and LTL HW were 10 mm. The number of the test specimens was 15.

3.9.3 Measuring Arrangements

The measuring was made according to SFS-EN 13647 and EN-1910 standards. The dimensions of the specimen were measured with calliper rule and weighed with a scale. The measuring conditions of the standard follows figure 22. While measuring, it was discovered that the moisture chamber did not follow the setting values. It made the test complicated and slowed down the measurements rather much. The measuring conditions are presented in figure 23. The duration of each conditioning period was 3 - 4 weeks. In each condition cycle the dimensions and weight were measured. The swelling test measuring equipments are presented in figure 24.

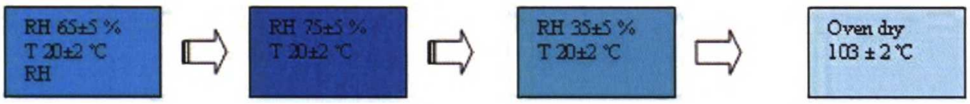

Figure 22. Required conditions in swelling test.

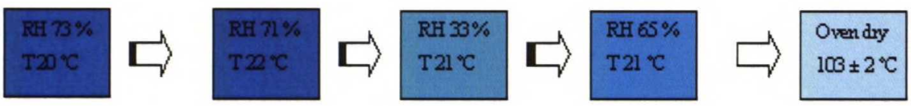

Figure 23. Measuring conditions in swelling test.

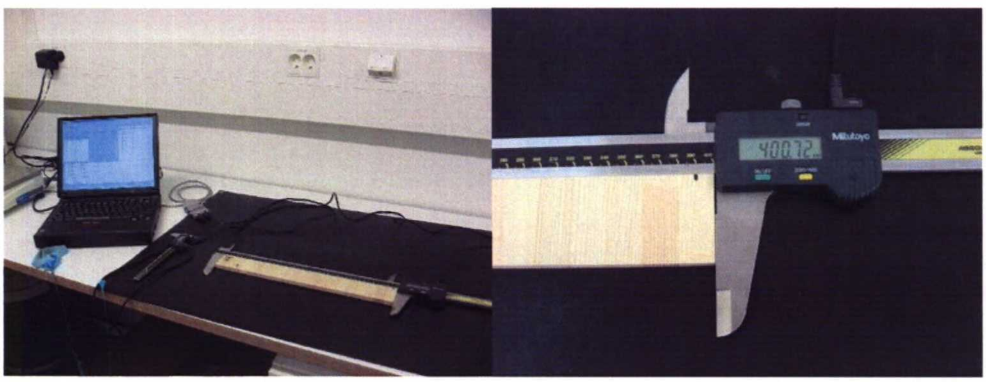

Figure 24. Swelling test measuring equipments.

The swelling was calculated according the EN-1910 standard, with formula *2*. The swelling from absolute dry to different relative humidity was calculated with formula *3*.

Swelling according EN-1910

$$dcr = 100\frac{(\frac{18}{15})D_h - D_d}{D_i}, \qquad (2)$$

where,

dcr is the cumulative relative dimensional change, in %,

D_i is the dimension after initial stabilization (RH 65 %),

D_d is the dimension after dry conditioning (RH 35 %),

D_h is the dimension after humid conditioning (RH 75 %).

$$\text{Swelling from abs. dry} = 100\frac{D_c - D_{dry}}{D_{dry}} \qquad (3)$$

where,

D_{dry} is the dimension of oven dry,

D_c is the dimension after specific conditioning (RH 35, 65 and 75 %).

3.9.4 The swelling effect of the glued lams

The wood material was 10 pieces of 95 mm wide pine board. The boards were cut to 3 specimens, each 50 mm long. One of the specimen (split board), was split to 4 pieces 20 * 20 mm, second one (pine EGB), was split also and glued together, reflecting as LTL, and the third one (pine board) was kept as it was. In figure 25 is presented the 3 different kinds of samples.

All samples were conditioned as in the **3.9.3** swelling test. In each condition the samples were measured. The each sample of the split board was measured by the width and the thickness. The pine EGB thicknesses were measured from 4 places, which were same places than the width of the split boards. Also the widths of the pine EGB were measured. The pine boards were measured in the same way. Thicknesses were measured in 4 places, which were the same places than the split boards thicknesses and also the width was measured.

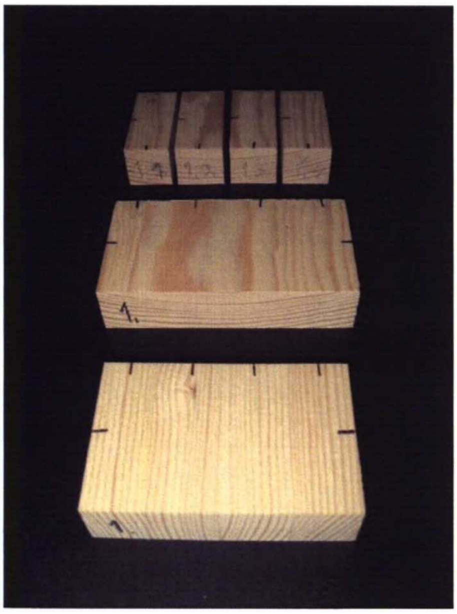

Figure 25. Samples of the swelling effect of the glued lams.

3.10 Determination of modulus of elasticity in bending and of bending strength

3.10.1 Material

The wood materials were conditioned in RH 65 % chamber. The wood materials were different for the test in parallel direction than in perpendicular direction. For the bending strength test in perpendicular direction, the test materials were 1, 2, 3, 4, and 5 (presented in appendix 2). The test materials for the test in parallel direction, were the same except number 5 (birch EGB), because the results were founded from the literature.

3.10.2 Test Specimens

The Modulus of the elasticity and the bending strength were measured according to SFS-EN 310 standard. The thicknesses of the samples were the same as the products have. Besides the LTL thicknesses were 20 and 30 mm, in test direction of parallel to the grain and 10 mm in the test of perpendicular to the grain. The thickness of the LTL HW was 10 mm, in both test directions of parallel to the grain and perpendicular to the grain. The number of the reference samples was 15.

3.10.3 Loading Arrangements

The modulus of elasticity (MOE) shows how stiff the material is and how big is the bending of the material. It is quite often that the structure bends more than it is allowed than the actual resistance to rupture is. If the material has the ability to regain its original form, it is called elasticity. When the load is less than a limit of deformation, the transformation is reversible, but if the load is getting greater and the material get broken, it is called limit of deformation. The modulus of the elasticity is growing linear with the density of the wood material. (Kärkkäinen, 2002)

The strength of the wood material is normally called the stress, which is in the limit of the rupture. The strength is in the wood material different in the different direction of the wood piece. The bending strength parallel to the grain is the most usual strength symbol of the wood material. (Kärkkäinen, 2002)

The modulus of elasticity in bending and bending strength were determined in the standard by applying a load to the centre of a test piece supported at two points. The modulus of elasticity was calculated by using the slope of linear region of the load-deflection curve; the value calculated is the apparent modulus, not the true modulus, because the test method includes shear as well as bending. The bending strength of each test piece was calculated by determining the ratio of the bending movement M, at the maximum load F_{max}, to the movement of its full cross-section. The rate of loading speed was that the maximum load was that reached within (60 ±30) s. The bending strength loading equipments are presented in figures 26 and 27.

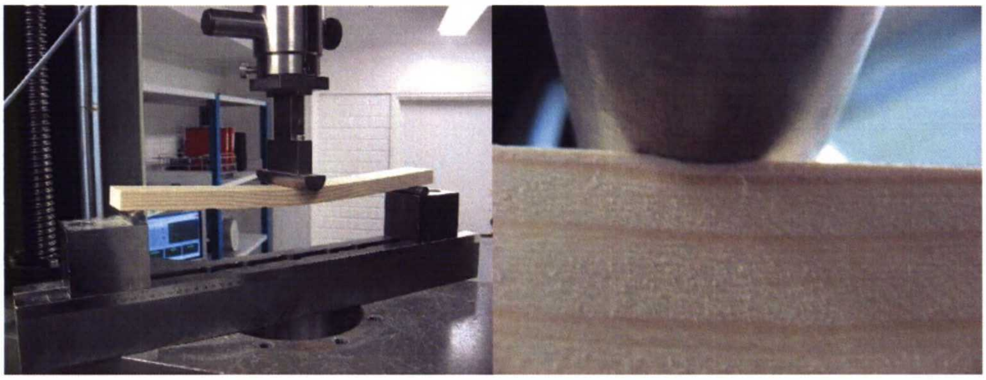

Figure 26. Bending strength loading equipments.

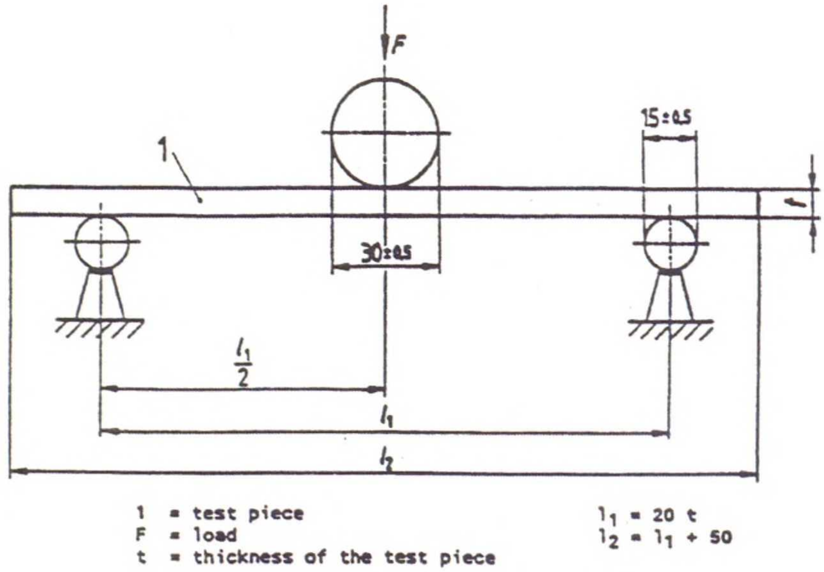

Figure 27. Bending strength loading equipments.

Modulus of elasticity

$$E_m = \frac{l_1^3 (F_2 - F_1)}{4bt^3 (a_2 - a_1)}, \qquad (4)$$

where,

l_1	is the distance between the centres of supports, in millimetres,
b	is the width of the test piece, in millimetres,
t	is the thickness of the test piece, in millimetres,
$F_2 - F_1$	is the increment of load on the straight line portion of the load-deflection curve. F_1 is 10 % and F_2 is 40 % of the F_{max},
$a_2 - a_1$	is the increment of the deflection at the mid-length of the test piece (corresponding to $F_2 - F_1$).

Bending strength

$$f_m = \frac{3F_{max} l_1}{2bt^2}, \qquad (5)$$

where,

F_{max}	is the maximum load, in Newtons,

l_1, b, and t are in millimetres as defined earlier.

3.11 The Moisture buffering test

3.11.1 Material

The test samples were conditioned first more than month in salt chamber RH 54 % (magnesium nitrate + distilled water). The test materials were 1, 3, 4, 5, 6, 7, 8, and 9 (presented in appendix 2).

3.11.2 Test Specimens

The test samples dimensions were 250 * 250 mm, if the product was narrower than 250 mm, then the test samples were cut so that the exposed face area were 0,0625 m^2. The samples were sealed on 5 out of 6 sides with aluminium tape. There were 5 test samples of each material. The thicknesses were the same as the products have, besides LTL thicknesses were 10 and 30 mm.

3.11.3 Measuring Arrangements

The moisture buffering test was measured applying *Nordtest method* (Rode, 2005). The test was a cyclic test, the samples were set 8 hours in humid condition (RH 75 %), and 16 hours in dry condition (RH 35 %). There were 10 cycles of both conditions. Between each cycle, the test samples were scaled. The apparatus of the cycling test is presented in figure 28. The calculated results were mass-change, Δm, per m^2 and per ΔRH. Two results of mass change were calculated for each cycle: one for the weight gain during absorption, and one for the weight loss during drying. The average between the absorption and desorption weight changes was calculated in each cycle. The Moisture Buffer Value (MBV) is calculated with formula 6 and 7. The result includes values only from cycles after 4^{th} period, which was required in the test method.

Moisture Buffering Value (MBV)

$$MBV_{out} = \frac{m_h - m_d}{A^2(c_h - c_d)}, \qquad (6)$$

and

$$MBV_{in} = \frac{m_d - m_h}{A^2(c_h - c_d)}, \qquad (7)$$

where,

MBV_{out} is the Moisture Buffering Value (the samples are drying), in $\frac{g}{m^2 \Delta RH\%}$

MBV_{in} is the Moisture Buffering Value (the samples are absorbing moisture), in $\frac{g}{m^2 \Delta RH\%}$,

m_h is the mass of the sample (humid condition), in grams,

m_d is the mass of the sample (dry condition), in grams,

A^2 is the exposed area, in square metres,

c_h is the humid condition RH, in %,

c_d is the dry condition RH, in %.

Figure 28. Condition apparatus of the moisture buffer test.

3.12 The Other Tests

3.12.1 The UV Light Effect

The effect of the UV light of the sun was tested with an applied method. One piece of LTL was pointed to south with 45 degree angle to the sun, in a place where it was not raining. The piece was 30 x 30 cm and the thickness was 6 mm. The idea was to confirm, what the effect of the sun is in 8 weeks period to the colour of LTL and its plain joints.

3.12.2 LTL with Narrower Lamellas

Originally the widths of the lamellas of the LTL were approximately 20 mm. With original width of the lamellas, the finger joints are seen evidently. The appearance of the LTL was considered with lamellas, which widths were approximately 8 mm. The finger joints were pointed as a zigzag. The hypothesis was that the appearance is better with narrower lamellas.

3.12.3 The Bleeding of the Resins in Different Temperatures

The bleeding of the resin of LTL and LTL HW was tested with an applied method. The hypothesis was that the resin of the pine starts to bleed approximately in 60 °C. The surfaces area of the wood samples were together approximately 3 m^2, the thicknesses of the LTL samples were 15 mm, and the thicknesses of the LTL HW samples were 28 mm.

The test method was to raise the temperature of the condition apparatus until both LTL and LTL HW bleeds resins, in conceivable indoor surface temperatures. The test started from 40 °C and finished to 80 °C. The temperatures were raised with 5 °C steps from 50 °C to 80 °C. The temperatures rose straight from 40 °C to 50 °C. The duration of the temperatures was 60 minutes.

3.12.4 Heat Treated LTL

The appearance of the LTL was considered with heat treating, and furthermore the durability of the plain joints was studied as well. The quantity of the test samples were 4 and the thicknesses were 15 mm and sizes of the samples were approximately 400 * 600 mm. The condition apparatus temperature was raised to 180 °C and the samples were set in. The duration of the heat treating was 1, 2, 3, and 4 hours.

3.13 Other Measurements

The moisture contents were calculated according SFS-EN 322.

$$mc = \frac{m_h - m_0}{m_0} * 100, \qquad (8)$$

where,

mc is moisture content,

m_h is the initial mass of the test piece,

m_0 is the mass of the test piece after drying.

The densities were calculated according SFS-EN 323.

$$\rho = \frac{m_h}{t * w * l} * 10^6, \qquad (9)$$

where,

ρ is the density of the test piece,

m_h is the mass of the test piece,

t is the thickness of the test piece,

w is the width of the test piece,

l is the length of the test piece.

3.14 Calculations of the test results

The mean value of the test results was calculated with formula 10.

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}, \qquad (10)$$

where,

$\bar{x}$ is the mean value of mean value of the measurements,

x_i is a single measuring result,

n is the number of measurements,

$\sum$ is the symbol of the sum.

The standard deviation of the test results was calculated with formula 11.

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x - \bar{x})^2}{n-1}}, \qquad (11)$$

where,

s is standard deviation,

x is a single measuring result,

$\bar{x}$ is the mean value of mean value of the measurements,

n is the number of measurements,

$\sum$ is the symbol of the sum.

The variances of the test results were calculated with formula 12.

$$VAR = \frac{s}{\bar{x}}, \qquad (12)$$

where,

s is standard deviation,

$\bar{x}$ is the mean value of mean value of the measurements.

The characteristic values of the test results were calculated with formula 12.

$$L^{q}_{5\%} = \bar{x} - t_n s, \qquad (13)$$

where,

$L^{q}_{5\%}$ is the characteristic value,

t_n is the Student coefficient for one sided 5 % liability,

$\bar{x}$ is the mean value of mean value of the measurements,

s is standard deviation.

The modelling of the regression analysis has calculated with formula 14.

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} +,...,+ \beta_p X_{i,p} + \varepsilon_i, \qquad (14)$$

where,

Y_i is the response,

$\beta_0, \beta_1, ..., \beta_p$ are estimated parameters,

$X_{i1}, X_{i2} +,...,+ X_{i,p}$ are known variables,

ε_i are independent experimental errors.

4 THE RESULTS AND DISCUSSIONS

4.1 The Interviews

4.1.1 The Results of the Interviews in Finland

In Finland, the reputation of the pine furniture has been spoiled with rustic style and bad quality. The main disadvantage of wood material of the pine is that there are quite much of resins. It can be a problem when treating the surface. The problem is bigger with the heartwood of the pine. All interviewed persons did not even believe that it is possible to separate the heartwood and sapwood in sawmills. The advantage to have heartwood in the panel is to give colour to the product.

The finger joints are a visual problem to furniture makers, because the appearance of the panel is cheap and the customers do not like finger joint neither. If the product has finger joints, the joints should be as a line, not as a zigzag. The size of the lamella is good now, the interviewed persons preferred thin lamella than wide 30 - 40 mm.

The radial surface is an advantage, because it resists more wearing and it swells less than normal EGB. The better surface resistance is proof, because there is more late wood than in tangential surface. The radial surface gives more homogenous and better outlook.

The interviewed persons thought that LTL is not suitable material for furniture or doors, and other objects that are close to eyes, because the finger joints. They could use it as a cleat or in hidden places.

The demands of furniture and interior panel are clear. The high visual properties are wanted and that the panel will not warp. The waxes and oils are preferred with the panels, but oils can make swell some PVAc glues.

4.1.2 The Results of the Interviews in Switzerland

The Finnish (Scandinavian) wood material has a good reputation in Switzerland. The pine is known, because of the reddish heart wood. To differentiate the Finnish pine of the others is also a disadvantage, because the Swiss people are ecological and can promote their domestic wood products. Normally the Swiss architects do not know the difference between coniferous trees, like pine and spruce. The architects divide the wood material to softwood and hardwood. The joinery industry chooses the wood material, between the coniferous species, what is growing near of the workshop. That is, because the transportation is very expensive in Switzerland. To compare pine and spruce, the pine has more resin and it is easier to machine. Because of the resin, there can be problems with the gluing or surface treating.

It is not unambiguous if heartwood is wanted in LTL or not. The heartwood can be an unnerving element in LTL, when the object is small. Anyway the heartwood can make a problem with surface treatments and gluing process. On the other hand, when the object is large (for example wall) the heartwood could give colour to the wall. In the joinery industry, the customer can think that there is a problem with the wood material, if the heartwood is seen or in worst case that the wood material is rotten.

The finger joints should be pointed as a line, at least when the object is small, because then the spectator concentrate on to the finger joints not to the whole object. Only disadvantage with the finger joints are, if those are as a line, is that the glue line can be seen under the surface treatment easier than with the zigzag option. The finger joints are not a problem, many people do not even know what a finger joint is and they just think that it belongs to the product. At least those two different kinds of finger joints can not be in the same product.

The knots are wanted in some products, because of the tradition of Swiss culture. The Swiss people are quite conservative and that is why new, modern product, without knots is maybe difficult to launch in Switzerland. On the other hand, young townspeople might be interested of pure new wooden panels.

If the LTL is made for to the wall, the lamellas size can be wider, but the 2 cm lamella seems to be an accepted size. If the lamella is thinner, the surface starts to looks nervous.

The radial surface of the LTL should be more stable than normal EGB. The hardness of the surface correlate with growing speed and also the grain direction has an influence of the hardness. In the tangential surface, the late wood can be loosening from the surface. The interviewed were surprised of the good quality of the LTL surface and hesitated, if the final product can be so good. If it is possible to keep the grains so direct, then the LTL is a high quality product.

4.1.3 The Results of the Interviews in Italy

Italy does not have wood culture, like in Scandinavia, because of the lack of forests. When co-operating with Italians, it is important to know their habits and respect those. E.g. Italians are used to have the shoes on at home, therefore the floors are made of stone based materials, laminate or hardwood. The wood products are wanted to discover as plastic ones; pale, pure, and knotless. The wood products are chosen by depending the price and appearance. The Architects in Italy have authority to choose the materials to the projects only, if the project is large. The most important demands of the wood products in Italy are price, applicability, and appearance.

Recommended surface treatments for LTL are oils, waxes, or other natural treatments. LTL without any treatments have to be in markets. As well boron salt is used for bleach the wooden surfaces. The comments of the LTL with narrower lamellas were not clear. LTL with narrower lamellas could be more stable.

4.2 The Surface Treatment Tests

The surface treatment tests were applied tests to perceive the usability and the appearance of the different treatments. The surfacing was made by hand, which was perhaps the cause of the spottiness of the dark colour of the waxes. The other reason for the spottiness is that the pigments of the waxes bunched together inside to the resin canals.

4.2.1 Wax

There was available Osmo color waxes and four maybe the most useful colours were "spruce", "birch", "beech" and transparent. Osmo color waxes spread easily and need two or three layers. If the layer is too thick, it needs grinding after next layer. The transparent colour makes the wood a little bit darker and the glue lines and resin spots will be emphasized. After a second layer the surface looks like varnished. The colour of the beech makes the heart wood and resin spots darker and that is why the surface needs primer first. The irregular surface absorbs more colours and then makes it spotty. Beech colour makes the wood look like a little bit dirty. The colour of spruce makes regular surface. The glue lines are hidden and it is difficult to say if there is a wax layer. After one layer and grinding, the surface feels smooth and silky.

4.2.2 Oil-wax

The oil-wax was also made of Osmo color. Spreading of the oil-wax was easier than the spreading of the wax. It also spreads easier, because it was more liquid. The surface dried fast and it was dry for touching after few minutes. The oil-wax made the wood material colour more yellowish.

4.2.3 Water Based Stains

Three really thin LTL panels (3 mm) were tested with three different colours of water based stains. The brand name was Clou. The colours were dark blue, pink, and orange. The colours were chosen to have a really dark and really bright colour. While treating, the panels cupped strongly, because the panels were treated only from one side. After drying the panels were plane again, but the surfaces were asperate, which means that they need to be grinded after the treatment. The water based stains were really easy to use and the equipments were easy to wash, only with soap and water. The disadvantages were that the finger joints opened a little bit. The dark blue colour hides that the LTL panel was made of pine and the glue line colour gets darker and jumps up. The wood's changes are more clearly seen with the pink colour. The orange colour changed the heart wood to ugly brown.

4.2.4 Soaker Based Stain

The soaker based stain was Tikkurila Dekko. The colour was "antique", which means dark grey. The dense surface of the colour was quite difficult to get. The finger joints did not open and the surface was not asperate, like in water based stains. The late wood coloured darker and a little bit spotty.

4.2.5 Beeswax

The beeswax was almost like butter, easy to spread, but it made a greasy surface, which did not dried totally. The surface felt soft and silky. The colour changed slightly to yellowish.

4.3 Brinell Hardness - Effect of the Grains Direction to the Brinell Hardness

The Brinell hardness was measured from both tangential and radial surface. The summary of the Brinell hardness results are presented in table 10 and figure 29. The characteristics values are calculated with formula *(7)*. The value of the Student coefficient for one sided 5 % liability was 1.67 when the number of the specimens were 66, according EN 1534. The mean moisture content of the samples was 12.5 %, and it was calculated with formula *(2)*.

The Brinell hardness was calculated by using diameter of the indentation, which is measured by calliper rule. The diameter depends always who is measuring and how. Therefore the Brinell results are not always reliable. Both radial and tangential Brinell test results were lower than the earlier test results of the LTL. It can be caused by wrong conditioning, measuring failure, or lower density.

Table 10. Summary of the test results.

	Radial	Tangential
HB_{mean}	13,1	12,4
HB_{05}	9,4	8,0
s	2,2	2,7
VAR	17 %	22 %
min	8,1	8,0
max	19,7	21,1

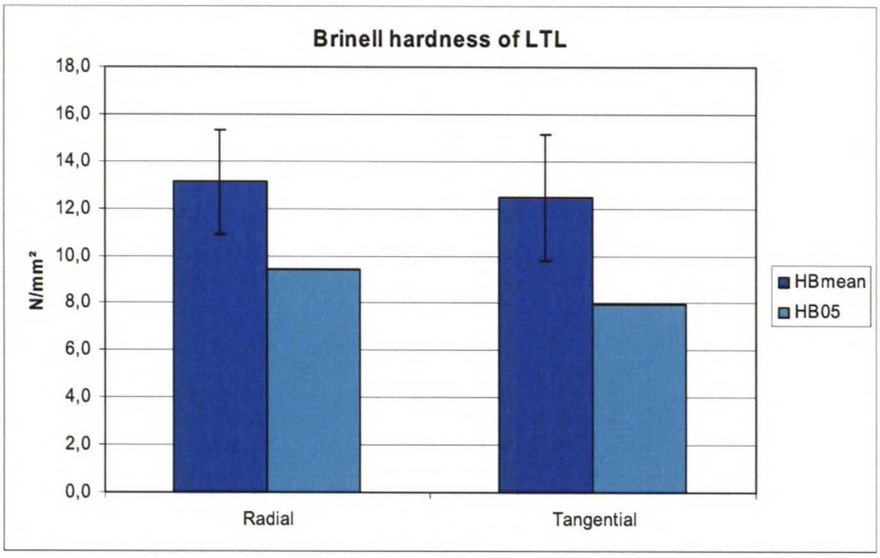

Figure 29. HB values, the mean and characteristics.

4.3.1 The correlation analyses

Correlations between density and Brinell hardness on both tangential and radial surfaces are presented in figure 30. Also trend lines and the R- squared values are presented as well.

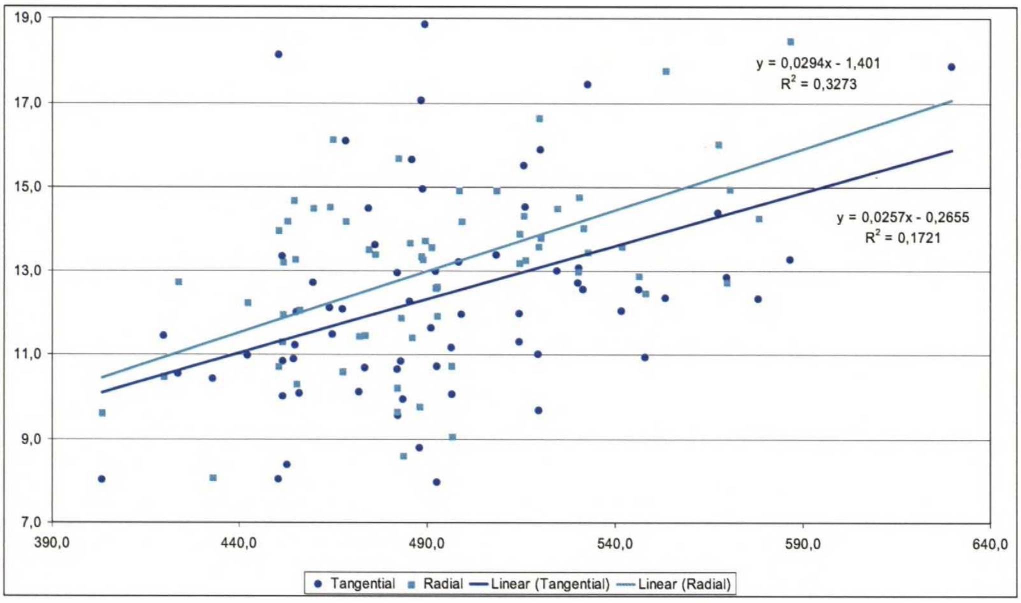

Figure 30. Tangential surface, correlation HB-Density.

The correlation analyses of the Brinell hardness on radial and tangential surfaces are presented in figures 31 and 32. As high the absolute value is, as much it is correlating with the variable. The negative correlation means that the variable is inversely proportional. The hardness results on tangential surface depend more on where the loading head hits the wood (early wood / latewood), than the density of the specimen.

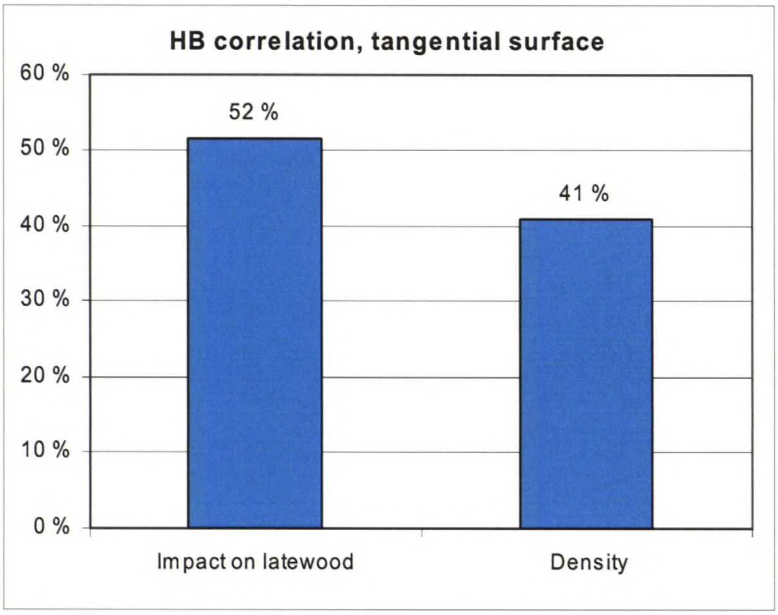

Figure 31. Correlation analyses of the tangential surface.

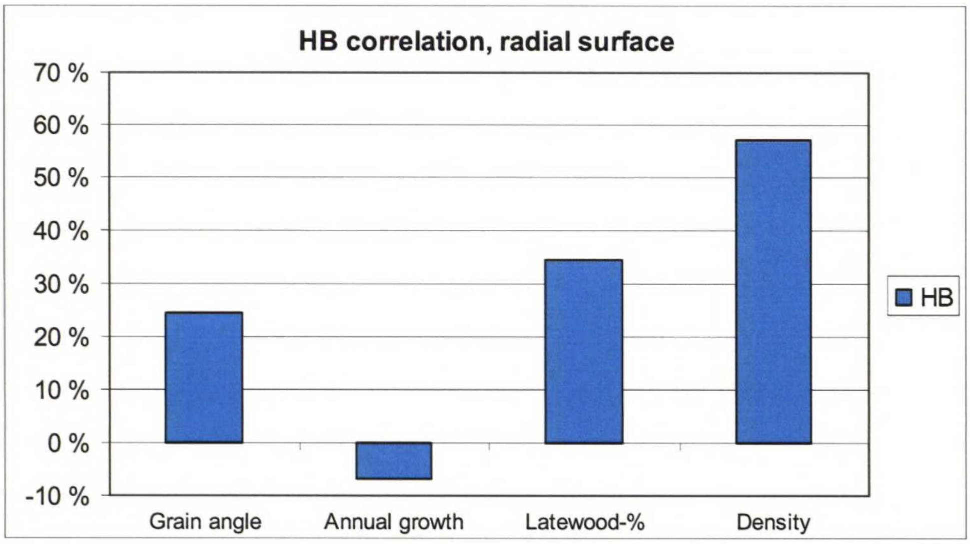

Figure 32. Correlation analyses of the radial surface.

4.3.2 Modelling Brinell Hardness

The suggestive Brinell hardness of the sap wood of the pine can be expressed with formula *15*. There are expressed all the variables, which were statistically significant (the P-value were lower than 0.05). The modelling process has been done with Microsoft Excel software and the formula *15* is created with formula *14*. More detailed Brinell hardness regression analysis is presented in appendix 4.

$$Y_i = -13{,}84 + 0{,}12\,X_G + 0{,}03\,X_D, \qquad (15)$$

where,

X_G is the grain angle of the surface of the wood material, in degrees,

X_D is the density of the wood material in kg/m³.

4.4 Assessment of Resistance to Impact

The results of the resistance to impact are presented in figure 33. As high the line is in the figure as soft material it is. LTL and Birch EGB have almost same values. More detailed results are presented in appendix 5.

The most interesting result of the impact test was that LTL and birch EGB have almost the same values, when the dropping level was lower than 250 mm. This caused perhaps the higher hardness of the latewood of the pine. The diameter of the impact spot was measured with the calliper rule. The measurements of the calliper rule are not reliable, but suggestive.

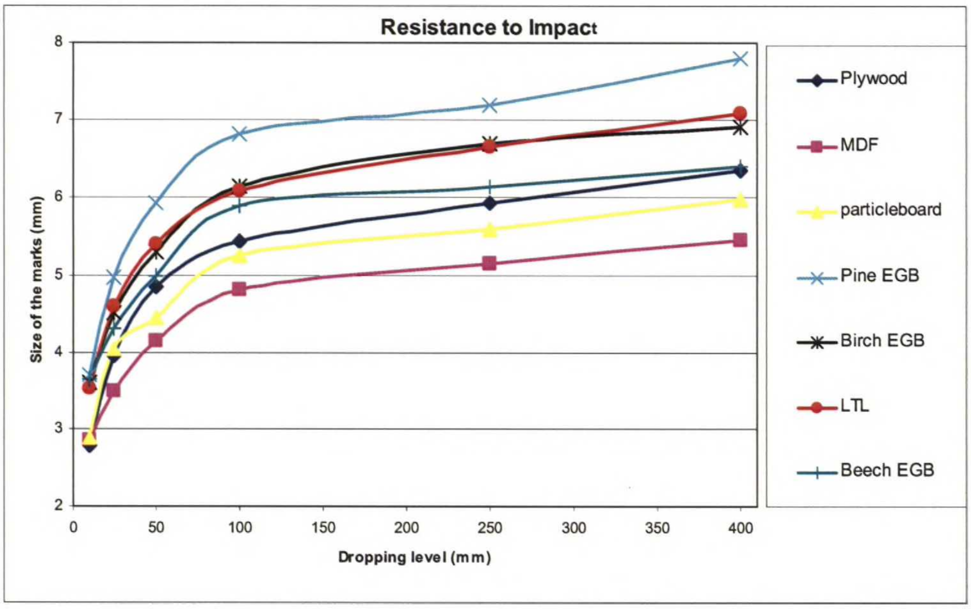

Figure 33. Results of the resistance to impact test.

4.5 Screw Hold Test

The results of the screw hold test are presented in figure 34. Both maximum screw hold loads and their standard deviations and the densities of the samples are presented. More detailed results are presented in appendix 6.

The screw holding forces were correlating the density with the solid wood panels. The dimension and the shape of the screw were chosen according the standard of the test method. Therefore the screw was not planned exactly to each material, but it was the same for apiece. Thus the screw might have not been equal for each material.

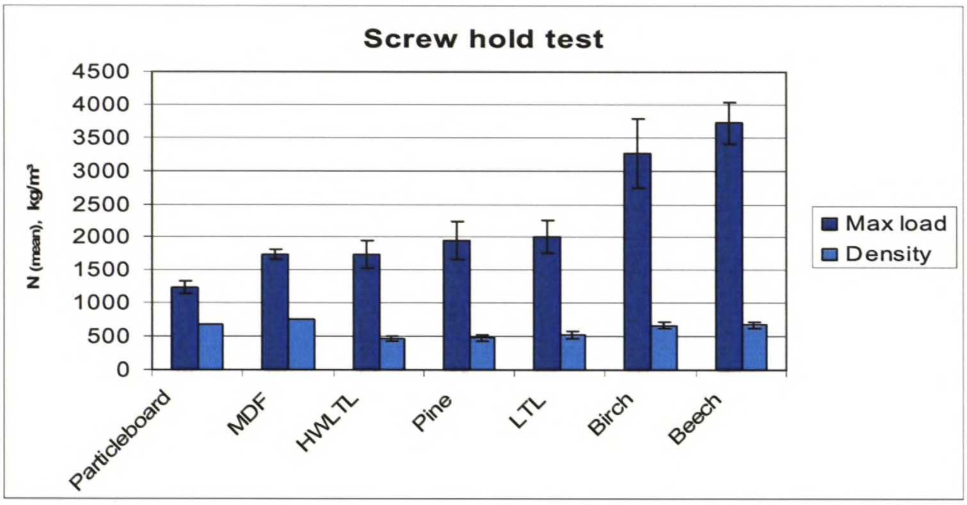

Figure 34. Results of the screw hold test.

4.6 Stability Test

The stability test included measurements of bow, cupping, spring, and twist. The measurements had been done in dry (RH 35 %) and humid (RH 73 %) conditions. More detailed results are presented in appendix 7, in the next pages are the summary of the results.

4.6.1 Bow

The results of the bow measurements are presented in figures 35 and 36. The figure 35 includes the absolute maximum bow result from the condition of RH 35 % or RH 75 %, the greater value is reported. In figure 35 is also the greater mean value of the bow, from the condition of RH 35 % or RH 75 %. The calculated deformations difference from the condition RH 35 % or RH 75 % is presented in figure 36, the greater value is reported.

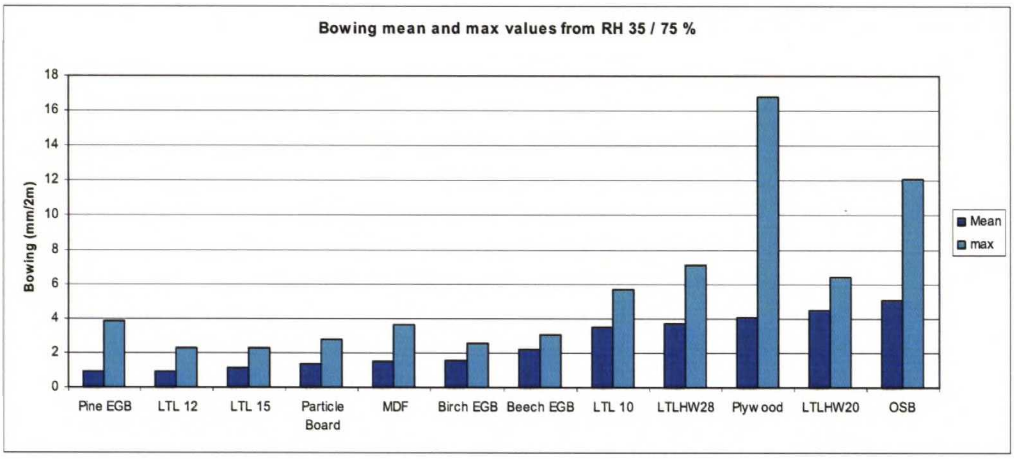

Figure 35. The absolute maximum and mean values of bow.

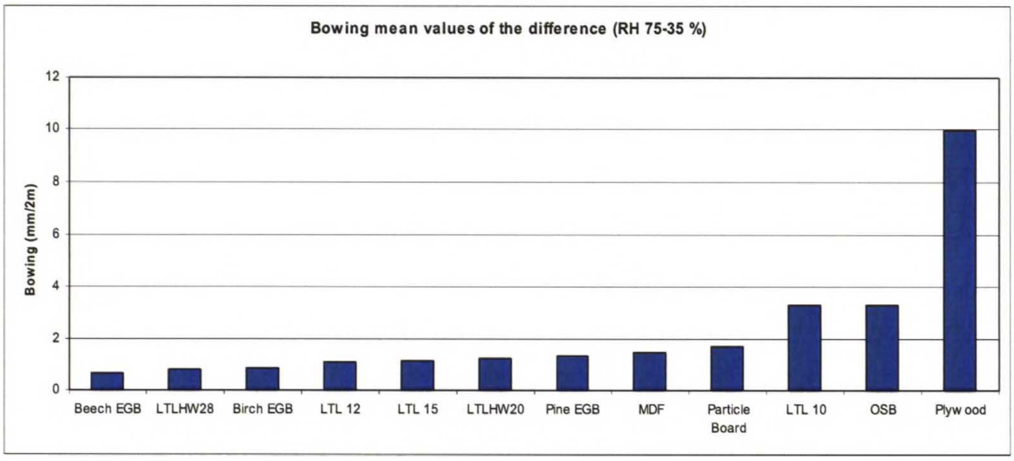

Figure 36. The calculated bow values differences of the deformations in RH 75 - 35 %.

The bows of the panels were highest with the layer constructed panels such as the birch plywood and OSB. Also the LTL HW have rather high absolute values that caused by the initial bows. The initial deformations of the samples have an effect to the absolute mean and maximum values of the bow. The initial bows were not measured. The mean values of the dry and humid climate difference are highest with the birch plywood, OSB, but also with the LTL, which thicknesses were 10 mm.

4.6.2 Cupping

The results of the cupping measurements are presented in figures 37 and 38. The figure 37 includes the absolute maximum cupping result from the condition of RH 35 % or RH 75 %, the greater value is reported. In figure 37 is also the greater mean value of the cupping, from the condition of RH 35 % or RH 75 %. The calculated deformations difference from the condition RH 35 % or RH 75 % is presented in figure 38, the greater value is reported.

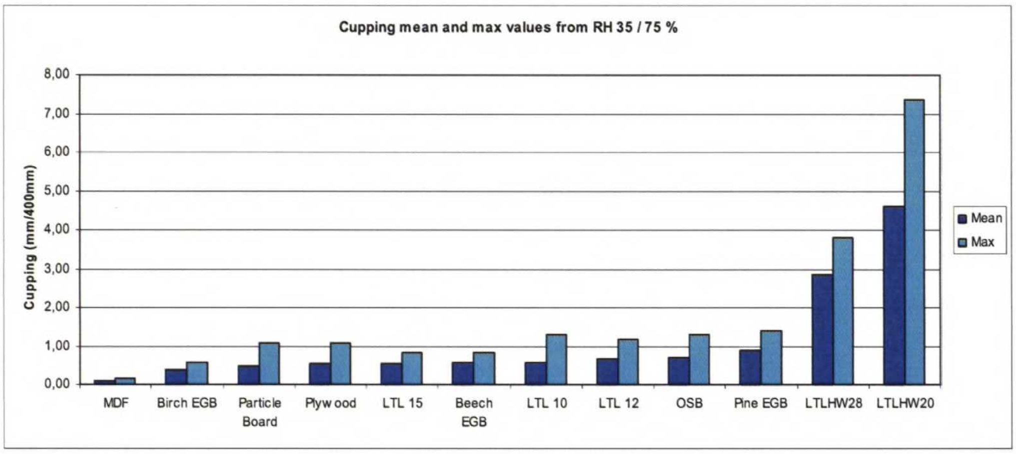

Figure 37. The absolute maximum and mean values of cupping.

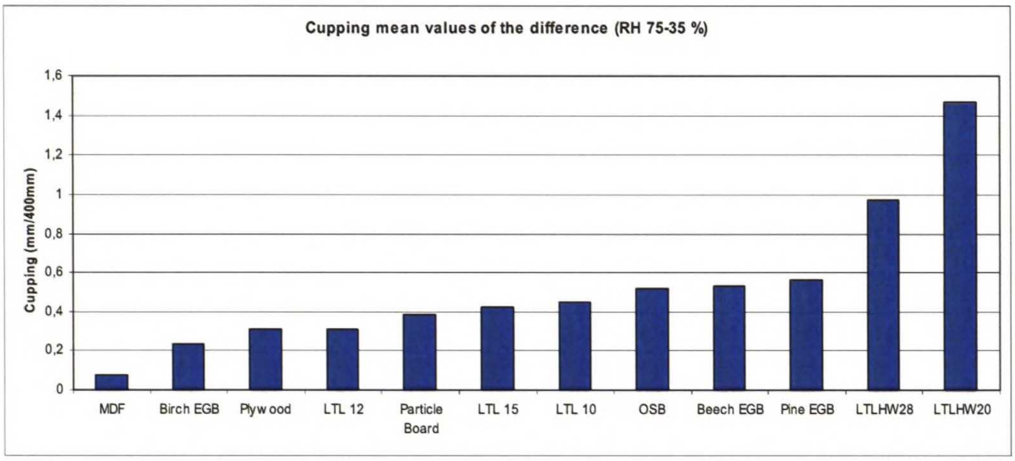

Figure 38. The calculated cupping values differences of the deformations in RH 75 - 35 %.

The cupping of the panels was highest with the LTL HW, with both thicknesses 20 and 28 mm. This might have been caused by the structure of the panel or the wrong hypothesis of the correction coefficient, which is explained in chapter **3.8.3.** The initial deformations of the samples have an effect to the absolute mean and maximum values of the cupping. The mean values of the dry and humid climate difference are the highest with both LTL HW 20 mm and 28 mm. The birch EGB mean values of the dry and humid climate difference are surprisingly rather low. This might have been caused by the well planned structure of the panel.

4.6.3 Spring

The results of the spring measurements are presented in figures 39 and 40. The figure 39 includes the absolute maximum spring result from the condition of RH 35 % or RH 75 %, the greater value is reported. In figure 39 is also the greater mean value of the spring, from the condition of RH 35 % or RH 75 %. The calculated deformations difference from the condition RH 35 % or RH 75 % is presented in figure 40, the greater value is reported.

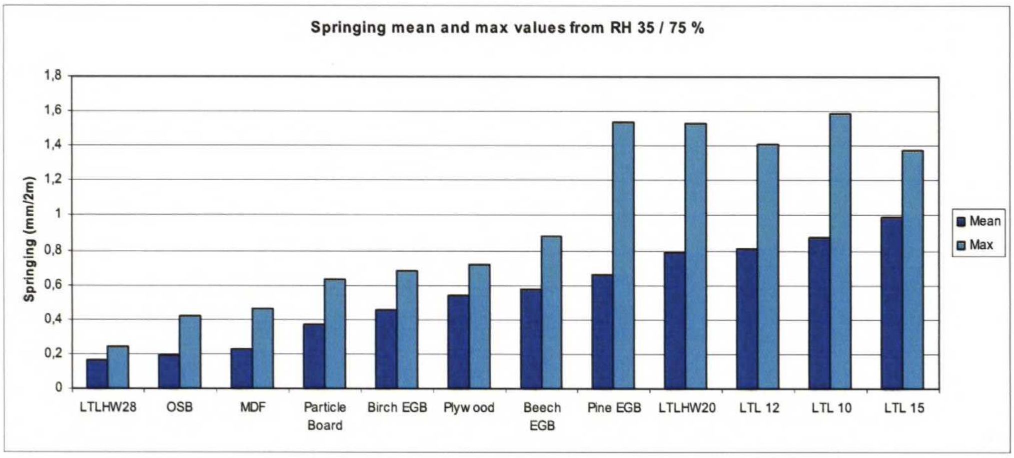

Figure 39. The absolute maximum and mean values of spring.

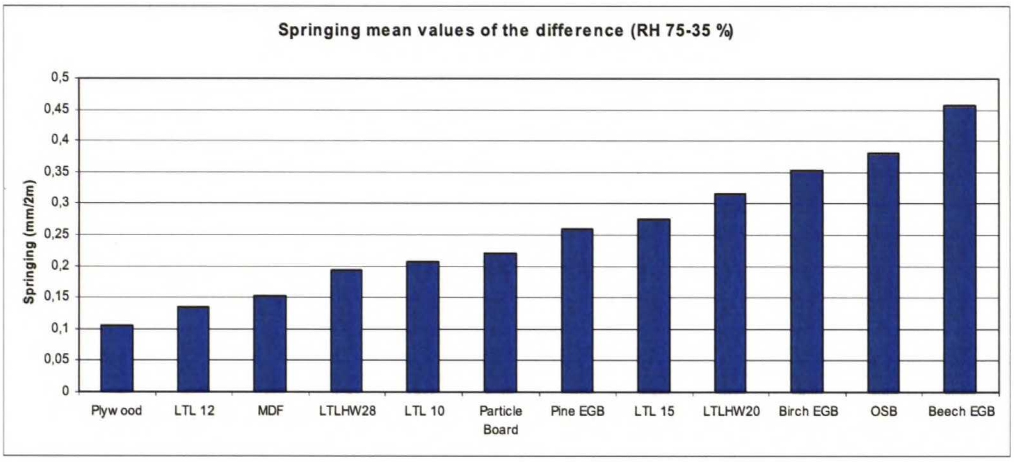

Figure 40. The calculated spring values differences of the deformations in RH 75 - 35 %.

The spring values were rather low, mean values of the dry and humid climate difference were lower than 0.5 mm with each material. The spring of the absolute mean and maximum values of the panels was the highest with the LTL and its all thicknesses. This was caused by the initial deformations of the samples. The initial spring was not measured.

4.6.4 Twist

The results of the twist measurements are presented in figures 41 and 42. The figure 41 includes the absolute maximum twist result from the condition of RH 35 % or RH 75 %, the greater value is reported. In figure 41 is also the greater mean value of the twist, from the condition of RH 35 % or RH 75 %. The calculated deformations difference from the condition RH 35 % or RH 75 % is presented in figure 42, the greater value is reported.

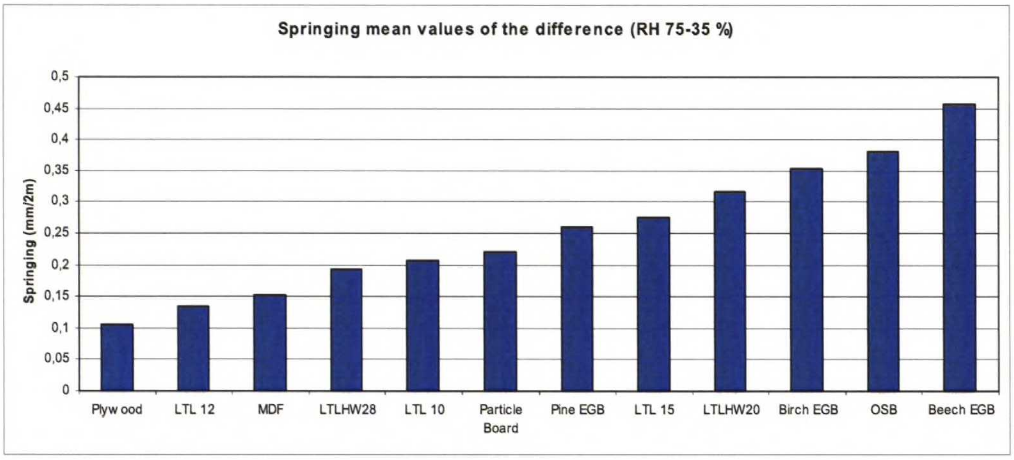

Figure 41. The absolute maximum and mean values of twist.

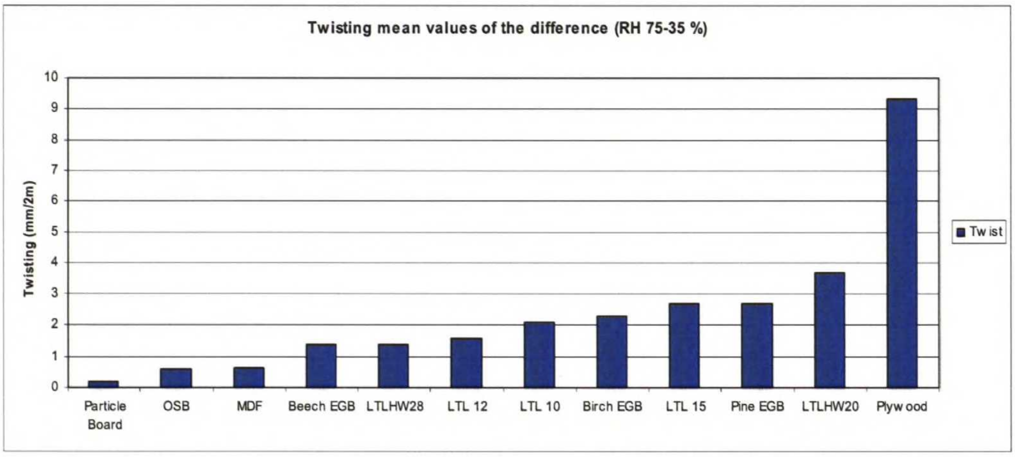

Figure 42. The calculated twist values differences of the deformations in RH 75 - 35 %.

The twist of the panels was highest with birch plywood. The absolute maximum values of the plywood were more than 30 mm. This was caused by the initial values and the structure of the plywood, the surface veneer of the plywood was perpendicular to the grain. Also the LTL HW 20 mm has rather high twist values that was caused by the initial twist. The initial bows were not measured, because of the problems of the moisture chambers. The mean of the twist values of the dry and humid climate difference were not correlating the thicknesses of the LTL. The LTL panels were sawn from the glue wood. Therefore the LTL panel could be from the edge of the glue wood or from the middle. This event might be the cause when the thicknesses were uncorrelated with the twist.

4.7 Swelling

The swelling results are presented in figures 43 and 44. More detailed results are presented in appendix 8. Those results are calculated from absolute dry to RH 33 %, RH 65 %, and RH 71 %.

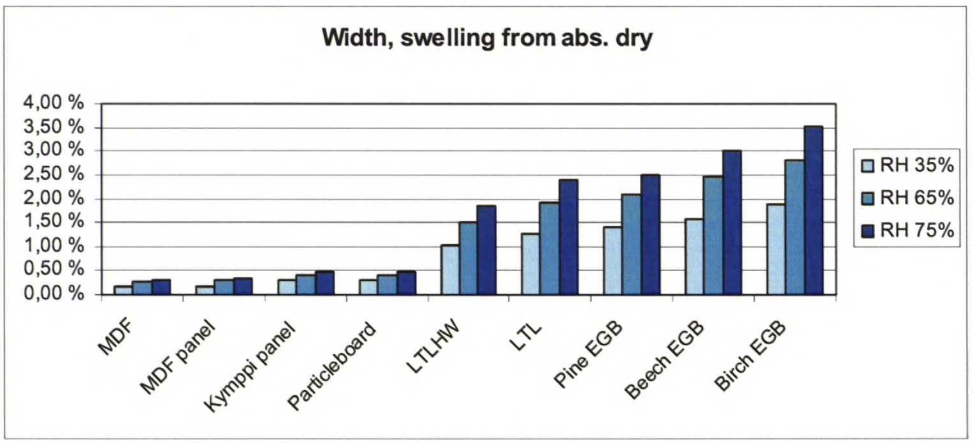

Figure 43. Swelling results of the width.

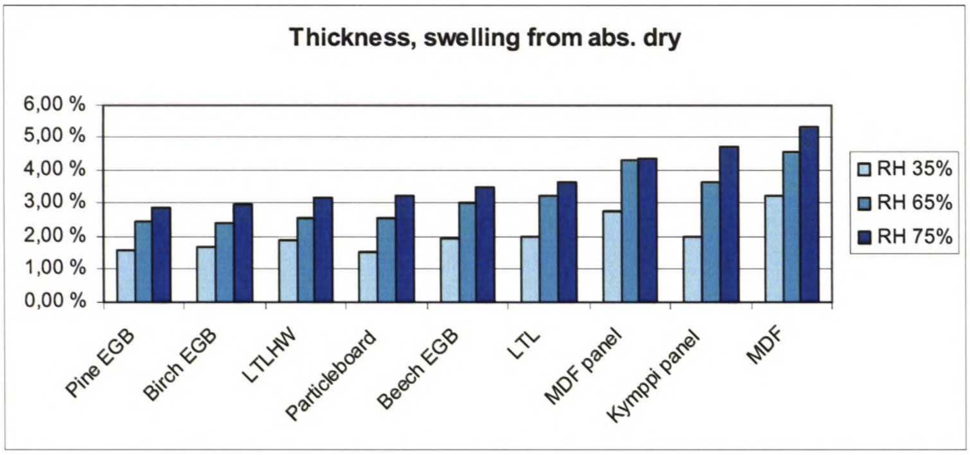

Figure 44. Swelling results of the thickness.

The swelling was calculated also according to SFS-EN 13647 and with formula *(2)*. These results are presented in figures 45 and 46.

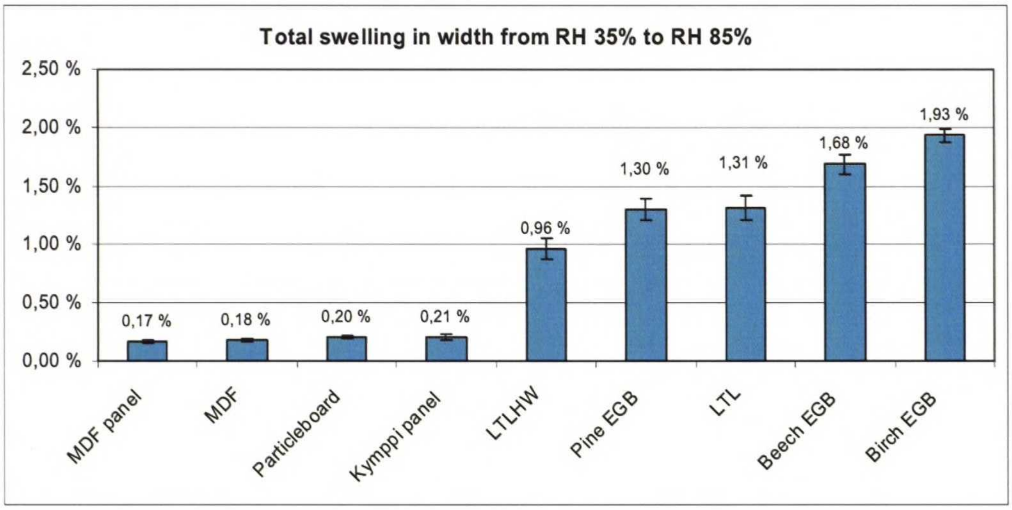

Figure 45. Swelling of the width (SFS-EN 13647).

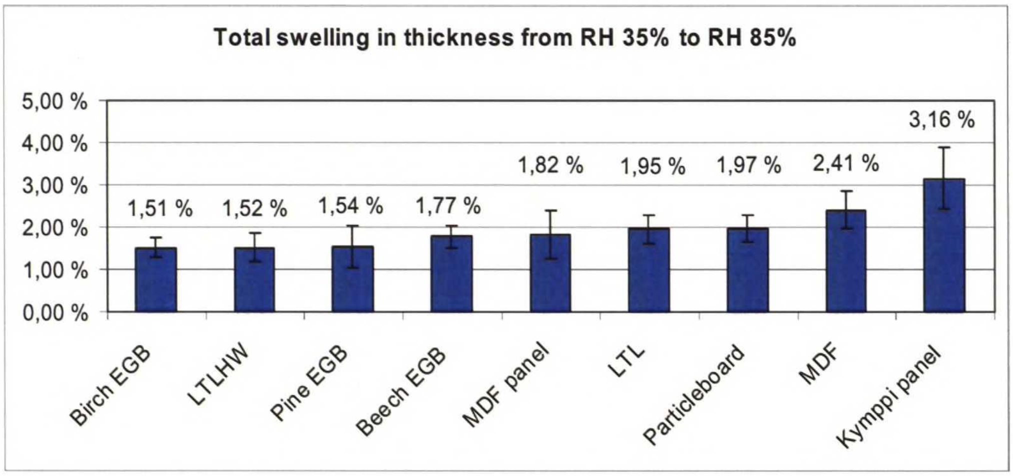

Figure 46. Swelling of the thickness (SFS-EN 13647).

The swelling result was quite much what was expected. The width swelling of the solid wood was correlating the densities. The higher swelling of the birch EGB than beech EGB was caused by tangential grain directions of the birch EGB. The standard deviation of the swelling in width was bigger with the solid wood panels than wood based panels (MDF / particle board). The swelling of the thicknesses were bigger with the based panels than solid wood panels and also the standard deviations were higher.

4.7.1 The swelling effect of the glued lams

The results of the swelling effect of the glued lams are presented in figures 47, 48, 49, and 50.

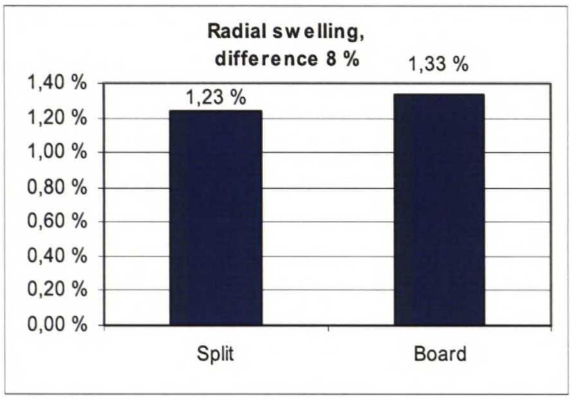

Figure 47. Radial swelling of the split board and board.

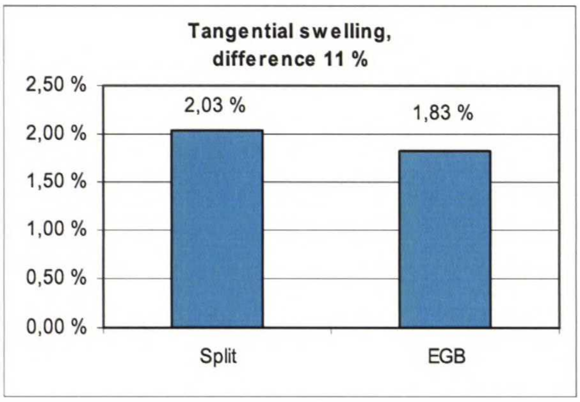

Figure 48. Tangential swelling of the split board and EGB.

The system effect is 4 samples sum of tangential swelling of the spilt board and those are compared to 1 board tangential swelling.

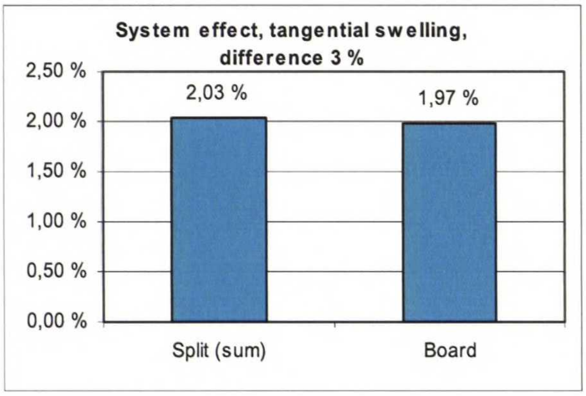

Figure 49. System effect of the tangential swelling.

The system effect is 4 samples sum of the radial swelling of the split board and those are compared to 1 EGB tangential swelling.

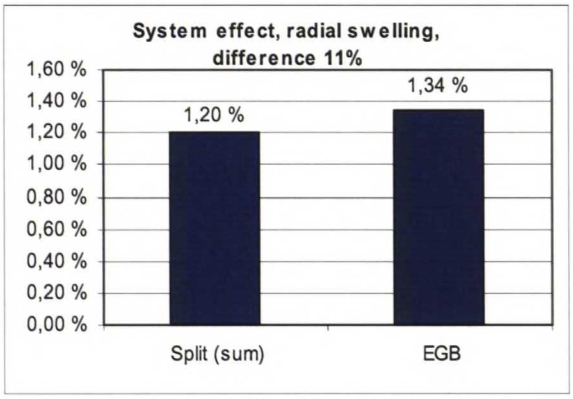

Figure 50. System effect of the radial swelling.

The swelling effect of the glued lams gave interesting results. The radial swelling, which means swelling of the thicknesses, is 8 % relatively bigger with the solid board than in split boards. Tangential swelling of the split board is 11 % relatively bigger than tangential swelling of the EGB. This event means that the glued EGB localized the swelling of the wood material in tangential direction

The tangential system effect swelling is 3 % relatively bigger with split board than with solid board. The result means that there is not big change in tangential swelling, if the sample is split.

The radial system effect is 11 % relatively bigger with glued EGB than in split board. The result surprised, the hypothesis was opposite. This means that gluing lams raise swelling in radial direction.

4.8 Determination of modulus of elasticity in bending and of bending strength

The results of bending strength are presented in figure 51 and 52. Also the standard deviation is marked to the chart. The literature values do not have standard deviation marks. More detailed results are presented in appendix 9.

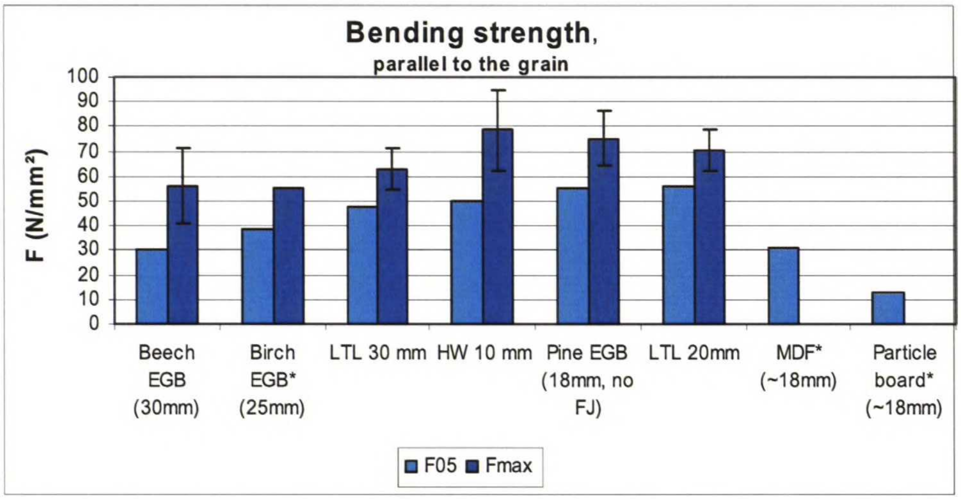

Figure 51. Characteristic bending strength, parallel to the grain. (* = values from literature part) (No FJ = No fingerjoints)

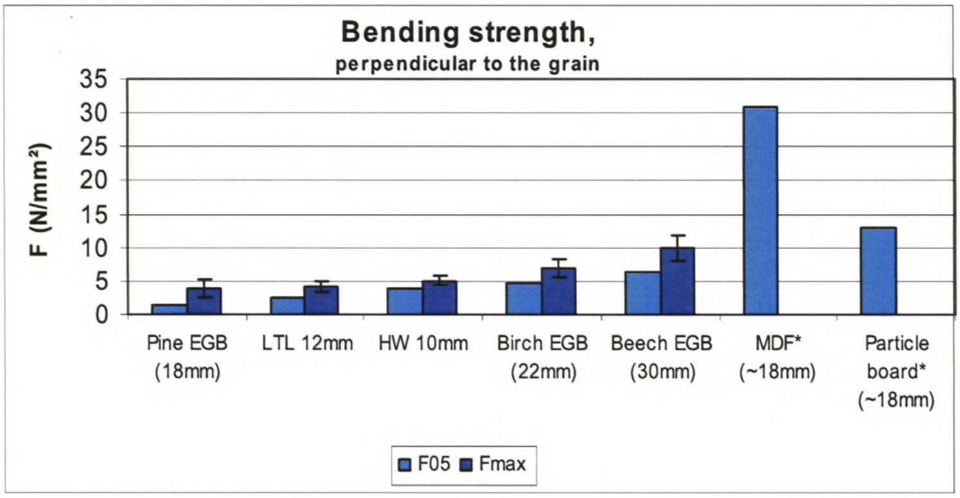

Figure 52. Characteristic bending strength, perpendicular to the grain (* = values from literature part).

The tests were made according EN-310, which means that the specimens were 50 mm width. The lamellas width of the beech EGB was 43 mm, lamellas of the LTL HW was 65 mm, and lamellas of the pine EGB was 45 mm. Therefore the bending strengths were so low with beech EGB and HW LTL. The high value of the pine EGB was caused by the not finger jointed lamellas. High standard deviation of the beech EGB and LTL HW was caused by the lamellas width. The plain joints opened in every 80 % of the samples of the beech EGB. The homogenous of the LTL is now advantage and gives good results of the bending strength in parallel to the grain. The low values of the solid wood panels bending strength in perpendicular to the grain were expected.

The results of modulus of the elasticity in bending are presented in figure 53 and 54. Also the standard deviation is marked to the chart. The literature values do not have standard deviation marks.

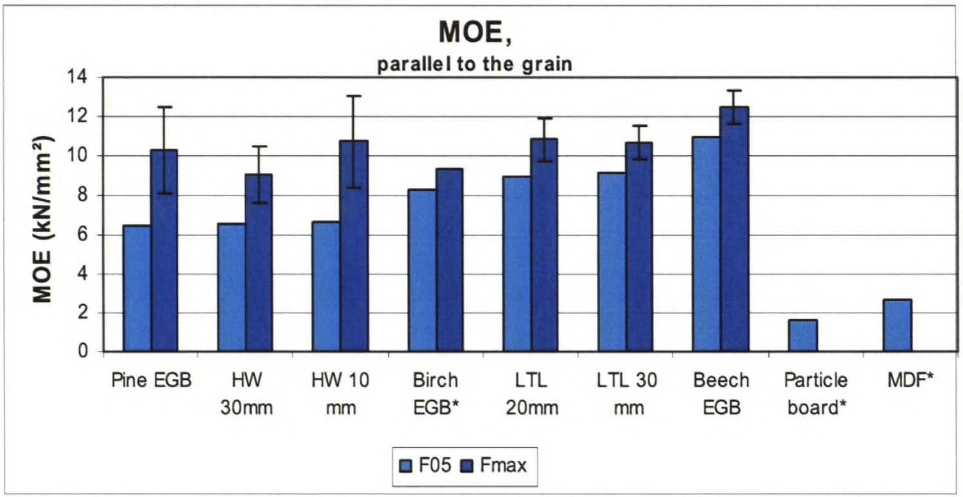

Figure 53. Modulus of elasticity, parallel to the grain (* = values from literature part, birch values: Myllynen, 2000).

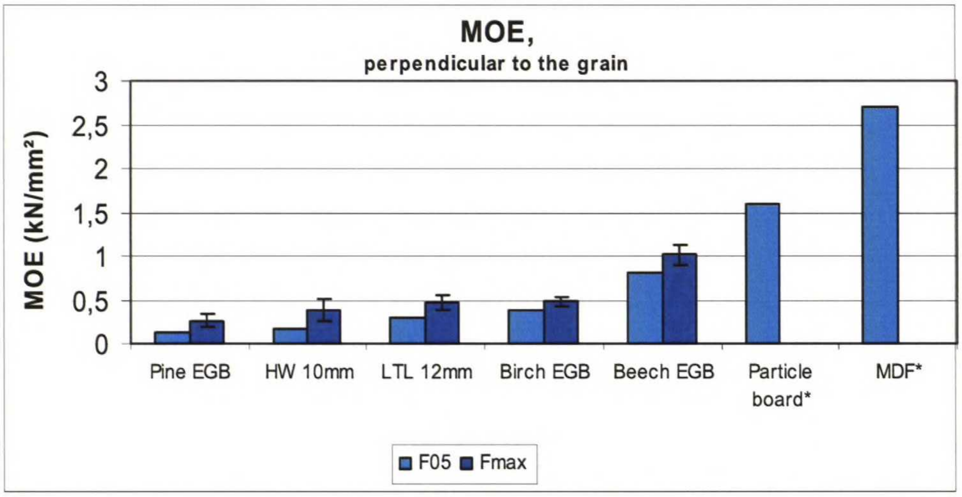

Figure 54. Modulus of elasticity, perpendicular to the grain (* = values from literature part).

The modulus of elasticity test results in parallel to the grain, the pine EGB and LTL have excellent results, close of the beech EGB. The low values of modulus of elasticity of the EGBs and LTL in perpendicular to the grain were expected. The high standard deviation values of the modulus of elasticity in parallel to the grain with the LTL HW and pine EGB was caused by the lamellas width comparing to the width of the sample.

4.9 Moisture Buffer Capacity

The results of the moisture buffering values are in table 11 and in figure 55. In table 11 is calculated the ingoing and outgoing moisture per square meters. Also the ingoing moisture per square meter in RH changes is calculated. In figure 56 are presented the humidity changes and the moisture buffering of LTL while cycles.

Table 11. The results of the moisture buffering test.

Material	out 16h g/m^2	in 8h g/m^2	in 8h $g/m^2 \Delta RH$-%
MDF panel	1,8	0,8	0,05
Kymppi panel	9,0	7,4	0,27
OSB	13,4	12,0	0,40
Plywood	30,8	28,0	0,91
Pine EGB	30,2	28,9	0,89
LTL 10mm	36,1	34,8	1,06
Birch EGB	36,4	31,4	1,07
LTL 30mm	38,6	34,0	1,13
Beech EGB	44,1	37,9	1,30

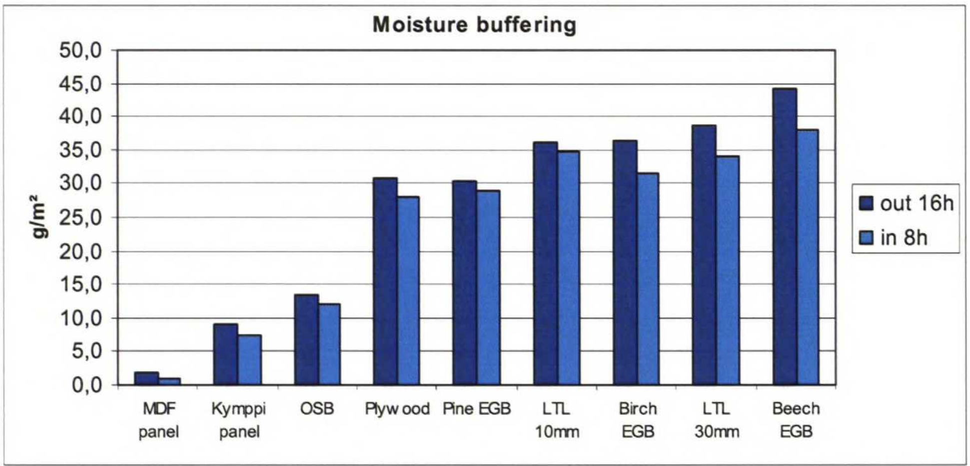

Figure 55. The results of the moisture buffering test.

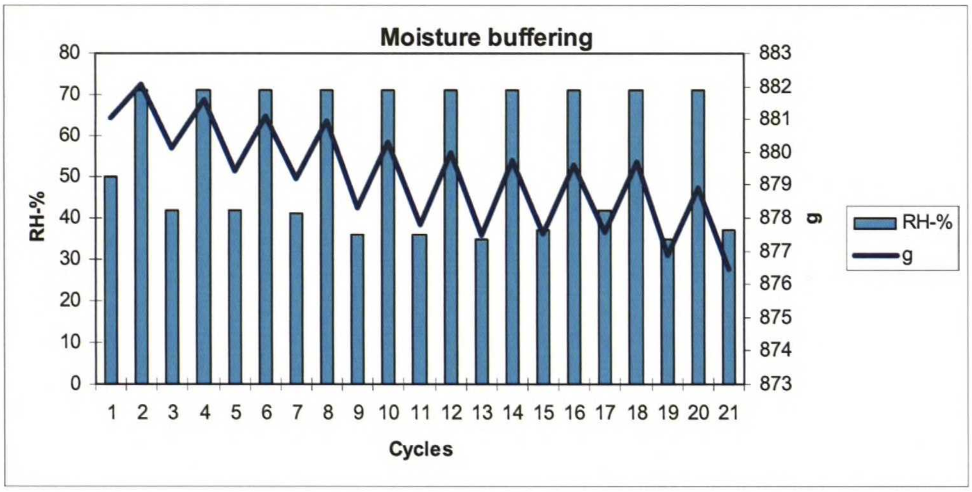

Figure 56. The RH-changes and weight of the specimen changes in the cycles.

The moisture buffering value (MBV) was correlating the densities of the solid wood panels. The radial surface of the LTL has higher MBV than EGB of the pine. The thickness has as well correlation with the MBV, until the penetration depth has reached. The birch plywood moisture buffering value was surprisingly high. The surface veneer has a big influence of the moisture buffer capacity of the birch plywood.

4.10 The Other Tests

The sample of the UV-light test was pointed to south. After the 8 week period the surface was much more yellow and there were great number of resin spots on it. In figure 57 is presented the LTL after 8 weeks of sun light and the other side which is lighter.

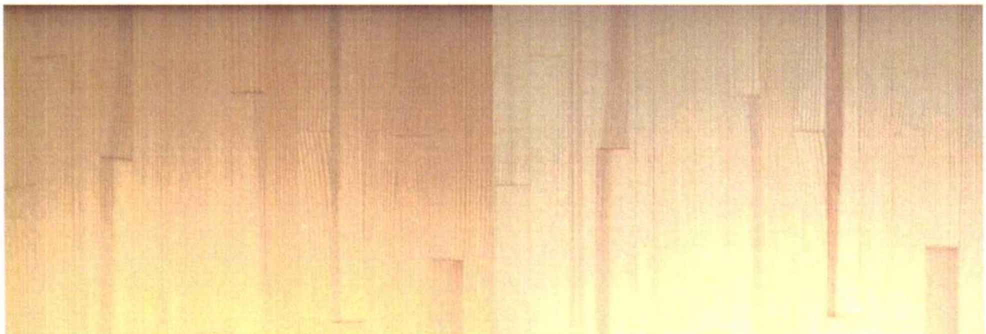

Figure 57. The results of the UV-light effect after 8 weeks (left), the other side on the right.

LTL with narrower lamellas (8 mm) is presented in figure 58. The original widths of the lamellas were 20 mm.

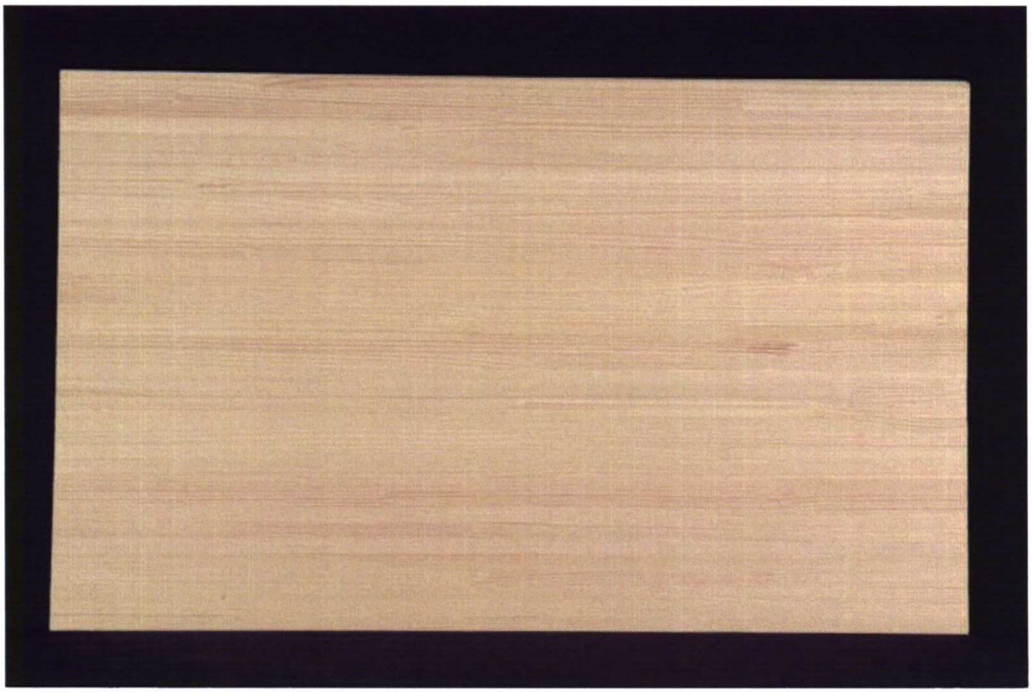

Figure 58. The LTL with narrower lamellas.

The test of the bleeding of the resins in different temperatures was applied test. The hypothesis was that the resin starts to bleed approximately in 60 °C. The test samples were LTL and LTL HW. The result was that the resins of the LTL started to bleed already lower than 40 °C and most of the resins came out approximately 50 °C - 65 °C. The resins of the HW LTL bled out much more evenly from the total surface, not from specific points as from LTL.

The heat treated LTL (180 °C) is presented in figure 59. The treating period was 4 hours. The plain joints of the lamellas opened or almost opened while treating. The used glue was polyurethane (PU).

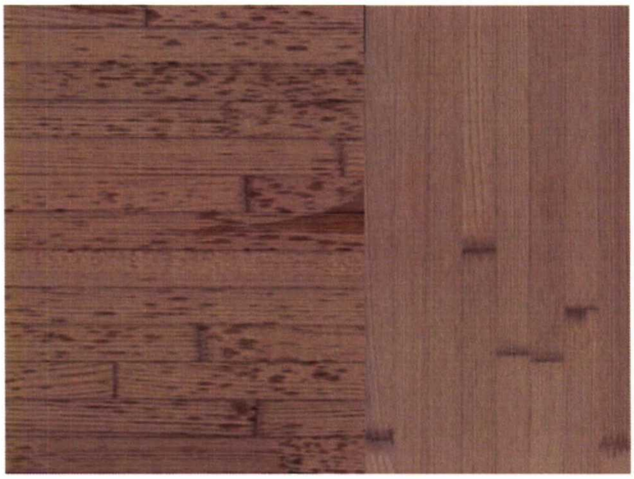

Figure 59. Heat treated LTL, left photo is after treating and the right one is after sanding.

5 CONCLUSIONS

The strategic objective of this research was to perform the technical tests, which are required for a new, conceivable wooden panel for furniture and interior. The furniture and interior panels required a great number of tests, such as strength and appearance experiments. The requirement of the furniture and interior panels are different, the furniture panel required more strength properties than interior panel and on the other hand the appearance of the interior panel is a great significance.

The experiments went technically well, except bending strength test method was wrong, the samples were too narrow and the plain joints contorted the results. The condition chambers had been assembled recently and the controller of the chambers had not been calibrated. As well, the interface of the controller showed incorrect values of the humidity. In consequence of those matters, the procedure of the experiments slowed down rather much. The design of the experiments was also changed and a number of experiments had been done twice, because of the problems of the moisture chamber.

The waxes and oils seem to fit well to LTL, only the dark colours of the waxes appear spotty and blurred. With different colour of the waxes it is possible to change the appearance of the LTL and its characters. The characters means now e.g. that the darker colour can hide the plain joints or finger joints. The natural waxes and oils are recommended, by the interviewed persons. The reasons are: natural components, maintainability, good moisture buffering, and the wood material will appear natural.

Now existing methods to measure wood materials hardness are difficult, because wood has many variables, which influence the hardness properties. Mostly influenced variables are density, latewood-%, grain angle, and the tested position of the wood. The Brinell test gave results that radial hardness is 13.1 N/mm² and tangential 12.4 N/mm², when using 500 N forces. Probably the difference is bigger, if lower forces are used. The wood material of birch is more than 50 % harder than LTL. Therefore the disadvantage of the LTL is the low hardness, when comparing it with birch and using Brinell hardness method.

The other way to test the surface hardness is the impact test. The test method is made for furniture, thus it is suitable for LTL. The 500 g cylinder was dropped from different levels on steel ball (diameter of 10 mm) and the mark was measured. The test result surprised, LTL and birch EGB got almost the same result, when the dropping level was lower than 250 mm. Therefore, hypothesis can be made that the radial surface of the LTL is durable, when using low forces.

A screw hold test was made to study if there are differences in screw holdings of the radial surfaces of the LTL and in the other materials. The hypothesis was that LTL might split easily, when assembling the screws. The result was that screw holding forces were correlating the density with the solid wood panels and LTL did not split, when the drilled hole was 3 mm and the screw diameter was 3.2 mm.

The deformations of the LTL in stability test were neutral. More samples would have been needed and the position of the LTL panel from the original glue wood is needed for comparing the edge and the middle position effect for the stability. The initial values of the deformations are needed for the comparing. Now those were not measured, because of the problems of the moisture chambers. The advantage of the LTL, comparing with birch plywood, is that it is more stable in its entirety. The market analyses of Stora Enso Timber will tell later who the main competitor is. After that it is logical to compare the deformation charts again.

The swelling test has two parts. In first part the swelling of the LTL was compared with other materials and in second part the system effect of the pine was measured (**4.7.1**). The width swelling of LTL was bigger than expected. It was almost the same than the EGB of the pine, without considering the way of the calculation. Smaller swelling, compared to pine EGB, was expected, because of the radial grain direction of the LTL. This event might have been caused by the higher density of the LTL or the swelling of the plain joints, because the LTL has more plain joints per centimetre than pine EGB. The density of the pine EGB was 6.7 % lower than the density of the LTL, but still the swelling of the pine EGB was 11.1 % lower than the swelling of the LTL in width direction. This event means that it is possible to do the hypothesis that the density of the wood material interacts more with the swelling properties than the grain angle of the EGBs. This hypothesis is positive, if the plain joints have no effect on the swelling properties of EGBs.

The results of bending strength parallel to the grain were good, but hardly comparable. The test method was wrong; it has been made for homogenous material, such as particleboard and MDF. The lamellas of the EGBs were so wide that the finger joints were interfered the results. LTL with the thin lamellas gave small deviations and therefore good characteristics values. The results of the bending strength perpendicular to the grain were what was expected; low with solid wood, much better with MDF and particle board. The homogenous and thin lamellas of the LTL increase the characteristic bending strength perpendicular to the grain. The results of the modulus of elasticity of the LTL in parallel to the grain were excellent, close of the beech EGB. The low values of modulus of elasticity results in perpendicular to the grain were supposed with the solid wood panels.

The moisture buffering value of the solid wood panels are excellent. Pine EGB and LTL are still in a different level. Pine EGB could absorb humidity 29 g / m^2 and 30 mm thick LTL 34 g / m^2 in 8 hour period from RH 35 % $\longrightarrow$ RH 71 %, which is 17

% more. That is caused by the porous radial surface of the LTL. This event is an important factor of indoor air quality. The Finnish building codes required that the ventilation changes 50 % of the indoor air per hour. With the porous building material the ventilation volume could be in theory decreased 10 % (Kokko, 2004). This event means an enormous savings of the energy. The porous indoor building materials are even more important e.g. in central Europe's countries, which do not have air ventilations and there is too cold to keep the windows open all year round.

The appearance of the LTL after the UV-light of the sun was good. After the test developed an idea that could it possible to stain the LTL surface straight yellowish that the sun does not have any more colour effect on it. The numbers of the resin spots were significant. It must be taken in account when using the LTL in straight sun light.

The test of the bleeding of the resins in different temperatures gave a significant result for the LTL. Already lower than 40 °C, the resins started to bleed out from LTL. The bleeding of the resins is a problem, if the LTL is in straight sun light, because the surface temperature rises.

The appearance of the LTL with narrower lamellas was particular significance. The finger joints were pointed as a zigzag and now the finger joints of the new LTL were almost invisible. The LTL with the narrower lamellas is emphatically more expensive to produce, but it will be a totally new product, a high quality product.

The heat treated LTL experiment was not successful. The colour changed after 4 hours in 180 °C, but the plain joints opened and turned dark brown. The appearance was not good, because of the dark plain joints. The heat treated LTL is possible to produce, with lamellas, which are heat treated already before gluing.

The density of the wood material is an important variable in numerous of experiments. Not exclusively in positive point of view, e.g. the swelling is correlating straight the density of the wood material, but generally the density of the wood material has a positive association. This event has to be taken into consideration, when planning the manufacturing of the LTL. Some products of the LTL density could be different than the others. E.g. the hardness of ceiling panel is not relevant; therefore the density could be lower, because the swelling of the ceiling panel is highly relevant.

The test results of the LTL have not any surprisingly particular weak points, but on the other hand there is a number of high-quality aspects. The SWOT-analysis of the LTL is made in table 12. If the information of the SWOT-analysis below will be consumed well, the LTL has a great opportunity to penetrate the markets of the high quality EGB of the wood material of the pine.

Table 12. SWOT-analyses of the LTL.

Strengths	Weaknesses
• Bending strength, parallel to the grain • Knotless • Lightness • Moisture buffer value • Visual properties / homogenous • Ecological	• Bending strength, perpendicular to the grain • The poor reputation of the pine • Hardness
Opportunities	**Threats**

• Many applications of the same product
• Long-lasting
    o Maintainability
    o Aesthetic ageing
• New material / product
• Well set price
	• Resinous
	• Badly planned commercialization
	• Badly planned finished products
	• Badly set price

5.1 Recommended Further Studies

After the Brinell and impact tests, it came out that the Brinell hardness is possible to calculate by using the depth of the indentation, not the diameter. Thus, the Brinell hardness is more liable, because the material testing equipment gives straight the depth indentations. The most interesting result of the impact test was that LTL and birch EGB have almost the same values, when the dropping level was lower than 250 mm. Therefore it is recommended to test the Brinell hardness with low forces and with the method, which uses the indentation's depth. Possible test forces are 100 N, 250 N and 400 N, for both LTL and birch EGB.

The screw holding test results were what was expected. The hypothesis is still that LTL splits more easily than the pine EGB, because of the radial grain direction. It is recommended to dimensioning the most suitable screw and the minimum screw distance from the edge of the LTL.

The stability test was made to samples, which were stabilized all through in different conditions. This reflect situation, when e.g. the interior panel is stabilized in summer / winter time on the wall. Recommended test is to concretize the actual interior wall, with different kinds of joints and fastenings and to change the humidity of the room e.g. RH 55 % $\rightarrow$ RH 20 % and measure the deformation after 8 hours. This event reflects when the heating start in cold winter night or in the building site, when the wet interior panels are assembled and the humidity of the room is low.

The cupping of the LTL is recommended to measure when the LTL has different kinds of surface treatment on only one side. This test gives results, if LTL needs two-sided surface treatment and, if it needs, then with which treatments.

The bending strength parallel to the grain of the LTL was good, but the test method was wrong. The recommended test is more practical; the panel size should be bigger that the finger joints do not contort the test as much. The possible width of the panel is 300 mm for the test.

From the interviews was developed an idea to have LTL wall panel as a partly-braced. A recommended study is to calculate: the brace volume in different thicknesses and joints, and the needed number of the fastenings.

The UV-light test changed the colour of the LTL to a calm yellowish. The yellowish colour could be possible to get right away with chemicals. The LTL will anyway turn darker without an UV-filter lacquer after while. This event solves the problem, when the customers do not want that the product changes its colour, while ageing.

The actual experimental wall, made of LTL is recommended to build to survey the appearance, evaluate the appearance with independent jury, for a marketing point of view, and to review the actual process ability.

The calculations of the penetration depth of the moisture buffering per day is recommended. The calculations show the minimum thickness of the LTL interior panel to get maximum moisture buffering capacity. The calculations are to optimise the right LTL thickness for production, if the moisture buffer effect is wanted.

6 SUMMARY

This study focused mainly on the technical suitability of the new glue lam product LTL (Laminated Timber Lumber). The strategic objective of this research was to perform the technical tests, which are required for the new, conceivable wooden panel for furniture and interior. The furniture and interior panels required a great number of tests, such as strength and appearance experiments. The requirement of the furniture and interior panel are different, the furniture panel required more strength properties than the interior panel and on the other hand the appearance of the interior panel has a great significance.

To achieve the aim; the literature part was concentrating to study already known characters of LTL and the main competitors. At the same time, interviews are conducted to determine the requirement for the furniture and interior panelling. The literature part includes also a part about potential surface treatments for LTL. The differences of the technical properties between LTL and the competitor panels are presented in the experimental part.

The main experiments, which have been performed, were the following:

- impact test,
- screw hold test,
- swelling test (thickness and width directions) and to clarify the properties of the EGB,
- stability test (bow, cupping, spring and twist),
- the modulus of elasticity in bending and of the bending strength (parallel to the grain and perpendicular to the grain),
- moisture buffering test.

There have been a number of reference samples of competitor panels, in all tests except the Brinell hardness which was measured only from the LTL. Some experiments were more for interior panels, some for furniture panels and some for both. The reference materials were chosen according to, if the test was for furniture or interior panel. As well the experiments included the LTL in different thicknesses.

Also a number of applied experiments were performed, such as:

- surface treatment test,
- UV-light effect of the LTL,
- the test of the bleeding of the resins in different temperatures,
- the test of the heat treated LTL,
- the test of the LTL with narrower lamellas.

The impact test was performed with a weight (500 g), which was dropped from different altitudes (10 – 400 mm) on a steel ball and the mark of the indentation was measured by calliper rule. The result of the impact test was almost the same with the LTL and the birch EGB. This event means that the surface hardness of the radial surface of the pine is nearly the same than the wood material of the birch, when using low forces.

The density of the pine EGB was 6.7 % lower than the density of the LTL, but still the swelling of the pine EGB was 11.1 % lower than the swelling of the LTL in width direction. The hypothesis was that the radial grain directions of the LTL will decrease the swelling in width direction of the panels. This event means that it is possible to do the hypothesis that the density of the wood material interacts more the swelling properties than the grain angle of the EGBs. This hypothesis is positive, if the plain joints have no effect on the swelling properties of EGBs.

The experiment of moisture buffering was a cycling test that included 10 cycles. The test was performed that the samples were 8 hours in a humid climate (RH 75 %) and 16 % hours in a dry climate (RH 35 %) and between the masses were scaled. The moisture buffering value of the solid wood panels are excellent. Pine EGB could absorb humidity 29 g / m^2 and 30 mm thick LTL 34 g / m^2 in 8 hour period in a humid climate, which is 17 % more. That is caused by the porous radial surface of the LTL. This event is an important factor of the indoor air quality. The Finnish building codes required that the ventilation changes 50 % of the indoor air per hour. With the porous building material the ventilation volume could be in theory decreased 10 %. This event means enormous savings of energy. The porous indoor building materials are even more important e.g. in countries of the Central Europe, which do not have air ventilation and there is too cold to keep the windows open all year round.

The appearance of the LTL with narrower lamellas was particularly significant. The finger joints were pointed as a zigzag and now the finger joints of the new LTL were almost invisible. The LTL with the narrower lamellas is emphatically more expensive to produce, but it will be a totally new product, a high quality product.

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Name:

Office and its address:

Work experience with wood?

Work experience with interiors?

Fingerjoints / knots

What do you think about wooden panels?

- Without knots? Why?
- Without finger joints? Why?
- With finger joints? Why?
- Should the finger joint be visible (as a zigzag) or as a line?

The lamella and its size

- What do you think about this product with thin lamellas (now 2 cm)?
- Should it be narrower or wider? Why?

Sap wood / heart wood

- Should there be only sap wood? Why?
- Should there be only heart wood? Why?
- Or mix of sap wood and heart wood? Why?

Radial surface

- Radial grain surface, is it an advantage or a disadvantage? Why?

Pine as a material

How people choose the wood material for interiors?

- (Pine, spruce, and larch) Why?
- Are there some problems to sell pine in X (country)? If yes, why?
- Is pine too soft for floors or stairs or some other uses?

This product (LTL)

- What would you like to know about this product, before you buy it? (Price etc.)
- Which surface treatment, you would use in this? Why?
- Where would you use this product?
- Which size you would like to have this product, for interior panel? Why?
- (length, width)
-

X (country)

- What are the main problems with wood products nowadays in X?
- Is there difficult to get some wooden products?
- Are wooden products too expensive in X?

Finally

- Could you use this product somewhere?
- Why to buy this product?
- What do you think about this product? And its architectonic sides?

Name	Commercial name	Width mm	Thickness mm	Length mm	Article
1	LTL	400	45	3000	8
1	LTL	400	30	3000	9
1	LTL	400	25	3000	2
1	LTL	400	20	3000	16
1	LTL	400	15	3000	16
2	LTL HW (panel)	280	28	6000	-
2	LTL HW (panel)	280	18	6000	-
3	EGB pine	600	18	2500	5
4	EGB beech	620	30	3660	5
5	EGB birch select plus	615	22	3000	5
6	OSB	1220	12	2440	1
7	MDF panel (listatalo)	150	10	2730	10
8	particle board panel + MEL	186	10	2520	18
9	Birch plywood BB WG	1220	12	2440	3
10	Particle board + MEL	585	18	250	5
11	MDF	1840	19	2750	3

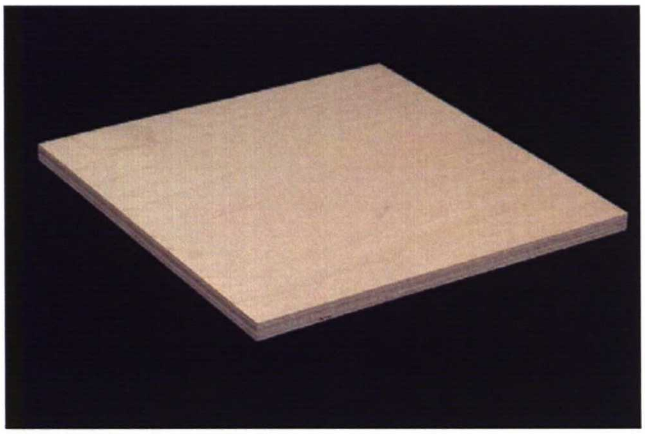

Figure 1. Birch Plywood. (Kinnunen, 2007)

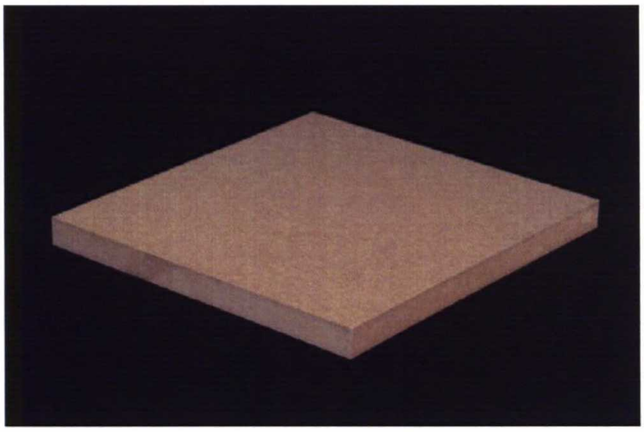

Figure 2. MDF. (Kinnunen, 2007)

Figure 3. OSB. (Kinnunen, 2007)

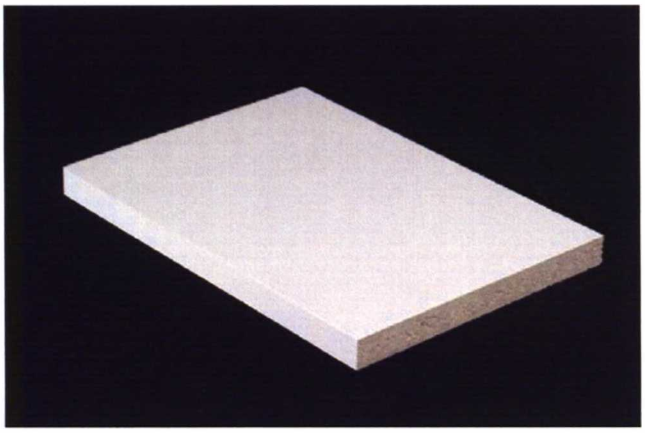

Figure 4. Particle board with melamine coating. (Kinnunen, 2007)

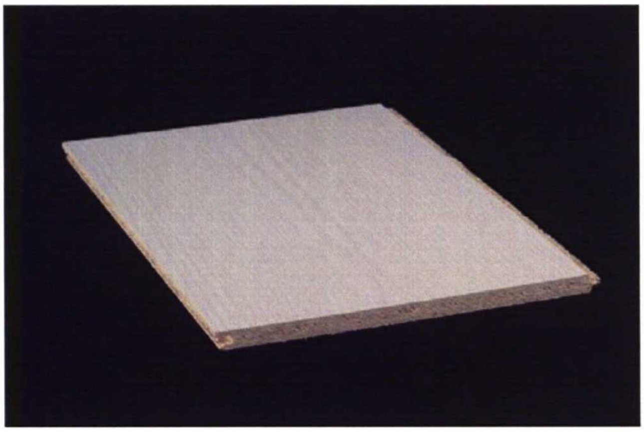

Figure 5. Particle board panel with melamine coating. (Kinnunen, 2007)

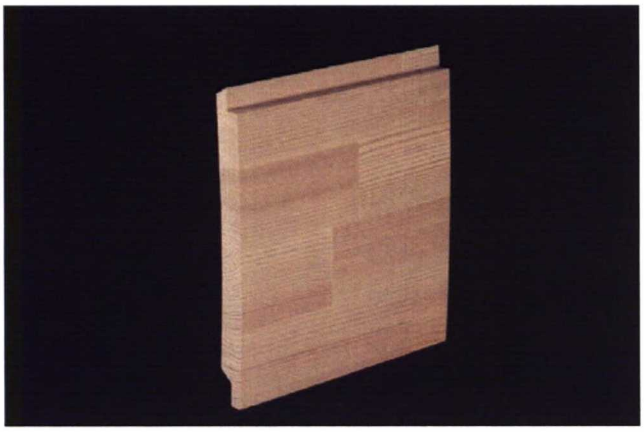

Figure 6. LTL HW panel. (Kinnunen, 2007)

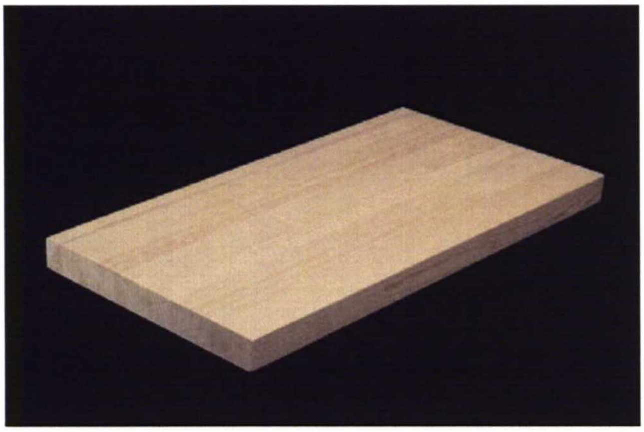

Figure 7. LTL. (Kinnunen, 2007)

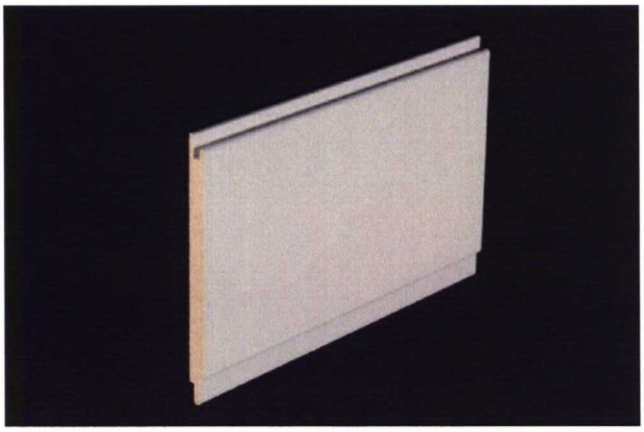

Figure 8. MDF panel with paint. (Kinnunen, 2007)

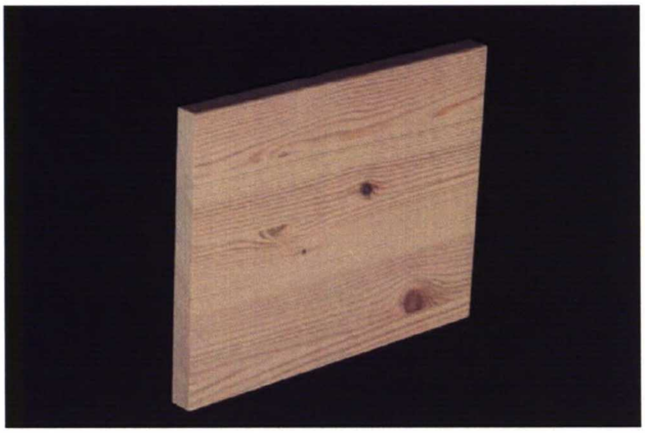

Figure 9. Pine EGB. (Kinnunen, 2007)

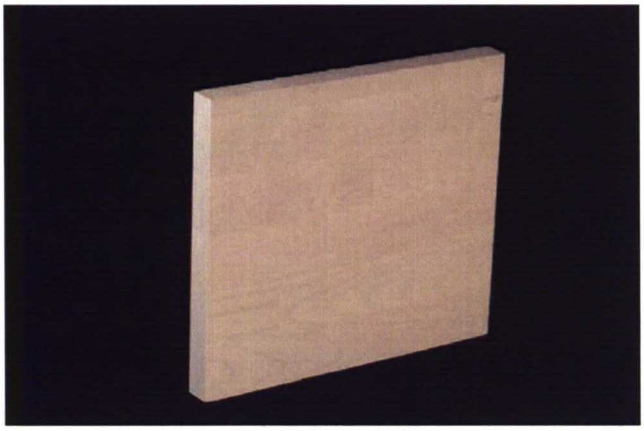

Figure 10. Birch EGB. (Kinnunen, 2007)

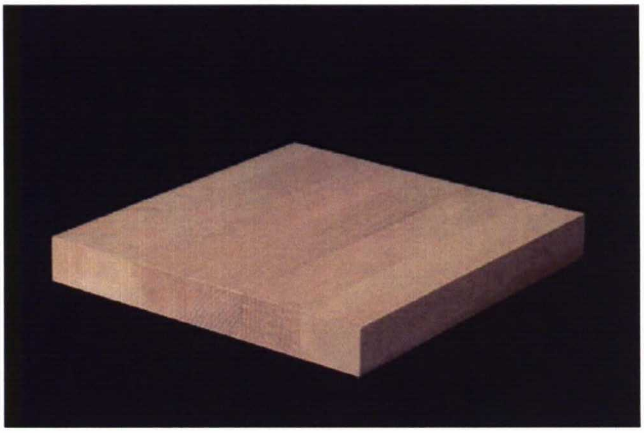

Figure 11. Beech EGB. (Kinnunen, 2007)

THE REGRESSIO ANALYSES OF THE BRINELL HARDNESS

APPENDIX 4

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,691621368
R Square	0,478340116
Adjusted R Square	0,461779485
Standard Error	1,629908986
Observations	66

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	153,467572	76,73378599	28,88417172	1,25229E-09
Residual	63	167,3660081	2,656603303		
Total	65	320,83358			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	-13,84235831	3,723469911	-3,717596392	0,00042977	-21,28311911	-6,4015975	-21,28311911	-6,4015975
Grain angle	0,119872075	0,028068708	4,270665914	6,69845E-05	0,063781238	0,175962912	0,063781238	0,175962912
Density	0,034105749	0,004800994	7,10389326	1,31685E-09	0,024511728	0,04369977	0,024511728	0,04369977

Material	MDF	Particleboard Melamine	Birch Plywood	Beech EGB	Birch EGB	LTL	Pine EGB
Dropping level (mm)	Average D (mm)	Average D (mm)	Average D (mm)	Average D (mm)	Average D (mm)	Average D (mm)	Average D (mm)
10	2,9	2,9	2,8	3,6	3,6	3,5	3,7
25	3,5	4,0	4,0	4,3	4,5	4,6	5,0
50	4,2	4,5	4,9	5,0	5,3	5,4	5,9
100	4,8	5,3	5,4	5,9	6,2	6,1	6,8
250	5,2	5,6	5,9	6,2	6,7	6,7	7,2
400	5,5	6,0	6,4	6,4	6,9	7,1	7,8

Sample	Max load (N)	Density (kg/m^3)
Particleboard	1242	675
MDF	1744	756
LTLHW	1733	466
Pine EGB	1948	476
LTL	2008	519
Birch EGB	3269	660
Beech EGB	3720	672

Max values
RH 35 %

Sample	Bowing (mm)	Cupping (mm)	Springing (mm)	Twisting (mm)
LTLHW20	6,42	7,37	1,53	10,94
LTLHW28	7,08	3,80	0,24	10,94
MDF	3,64	0,13	0,46	0,60
OSB	10,41	0,85	0,38	3,40
Plywood	16,82	0,76	0,57	32,51
Particle Board	1,67	1,08	0,55	1,47
Birch EGB	2,15	0,56	0,27	4,77
Beech EGB	2,37	0,40	0,88	1,51
Pine EGB	3,81	1,40	1,26	7,89
LTL 10	3,20	0,91	1,59	3,09
LTL 12	2,25	1,07	1,41	4,43
LTL 15	2,30	0,76	1,37	6,74

Mean values RH 35 %

Sample	Bowing (mm)	Cupping (mm)	Springing (mm)	Twisting (mm)
LTLHW20	5,32	4,61	0,79	5,34
LTLHW28	3,84	2,87	0,15	2,94
MDF	2,01	0,06	0,23	0,35
OSB	4,44	0,42	0,17	1,68
Plywood	8,28	0,53	0,48	12,45
Particle Board	1,25	0,41	0,37	1,19
Birch EGB	1,39	0,38	0,18	3,63
Beech EGB	1,88	0,23	0,57	0,53
Pine EGB	2,17	0,88	0,57	4,16
LTL 10	2,10	0,36	0,88	1,96
LTL 12	1,51	0,67	0,81	3,00
LTL 15	1,56	0,54	0,99	3,23

Max values RH 75 %

Sample	Bowing (mm)	Cupping (mm)	Springing (mm)	Twisting (mm)
LTLHW20	5,17	5,95	1,39	6,36
LTLHW28	6,32	3,11	0,19	5,64
MDF	2,55	0,15	0,35	2,66
OSB	12,06	1,31	0,42	3,94
Plywood	9,26	0,49	0,72	7,46
Particle Board	2,79	0,55	0,63	1,51
Birch EGB	2,55	0,43	0,68	3,13
Beech EGB	3,03	0,83	0,36	3,21
Pine EGB	2,70	1,35	1,54	3,25
LTL 10	5,69	1,31	1,52	4,51
LTL 12	1,23	1,16	1,25	2,76
LTL 15	1,56	0,82	1,23	3,87

Mean values RH 75 %

Sample	Bowing (mm)	Cupping (mm)	Springing (mm)	Twisting (mm)
LTLHW20	4,46	3,68	0,49	4,63
LTLHW28	3,72	2,47	0,17	3,63
MDF	1,52	0,08	0,23	0,80
OSB	5,08	0,71	0,19	1,88
Plywood	4,08	0,35	0,54	4,46
Particle Board	1,35	0,47	0,33	1,31
Birch EGB	1,59	0,37	0,45	1,48
Beech EGB	2,20	0,56	0,33	1,67
Pine EGB	0,90	0,78	0,66	2,10
LTL 10	3,45	0,59	0,86	3,23
LTL 12	0,96	0,63	0,80	1,95
LTL 15	1,13	0,54	0,84	3,11

Max values of difference (RH 75-35 %)

Sample	Bowing (mm)	Cupping (mm)	Springing (mm)	Twisting (mm)
LTLHW20	1,97	2,58	0,53	5,67
LTLHW28	1,41	1,49	0,42	5,60
MDF	2,78	0,13	0,49	2,65
OSB	4,18	0,78	0,33	1,33
Plywood	18,66	0,59	0,23	25,05
Particle Board	2,84	0,83	0,37	0,30
Birch EGB	1,51	0,33	0,46	3,63
Beech EGB	1,51	0,72	0,67	3,14
Pine EGB	1,96	1,08	0,34	4,96
LTL 10	7,78	1,09	0,39	3,06
LTL 12	1,88	0,64	0,22	2,99
LTL 15	1,76	0,76	0,38	3,49

Mean values of difference (RH 75-35 %)

Sample	Bowing (mm)	Cupping (mm)	Springing (mm)	Twisting (mm)
LTLHW20	1,21	1,47	0,32	3,79
LTLHW28	0,83	0,97	0,19	2,89
MDF	1,47	0,08	0,15	0,63
OSB	3,29	0,52	0,38	0,59
Plywood	9,99	0,31	0,11	9,33
Particle Board	1,71	0,38	0,22	0,18
Birch EGB	0,84	0,23	0,35	2,27
Beech EGB	0,64	0,53	0,46	1,39
Pine EGB	1,32	0,57	0,26	2,71
LTL 10	3,28	0,45	0,21	2,09
LTL 12	1,08	0,31	0,13	1,60
LTL 15	1,15	0,42	0,28	2,71

Sample	Density	Moisture content (%)		
	(kg/m³)	RH35%	RH65%	RH75%
Beech EGB	685	7,3 %	10,5 %	12,4 %
Birch EGB	620	7,0 %	9,9 %	12,3 %
Kymppi panel	740	6,6 %	9,2 %	10,9 %
LTL	497	7,9 %	11,0 %	13,4 %
LTLHW	450	7,6 %	10,7 %	12,7 %
MDF	763	6,2 %	8,1 %	9,2 %
MDF panel	708	5,3 %	7,0 %	7,9 %
Particleboard	672	6,2 %	8,2 %	9,3 %
Pine EGB	465	7,6 %	10,5 %	12,4 %

Sample	Thickness Swelling from abs. dry (%)			Swelling (SFS 13647)
	RH 35%	RH 65%	RH 75%	Thickness
Beech EGB	1,97 %	3,04 %	3,49 %	1,77 %
Birch EGB	1,69 %	2,41 %	2,97 %	1,51 %
Kymppi panel	1,99 %	3,64 %	4,72 %	3,16 %
LTL	1,98 %	3,26 %	3,65 %	1,95 %
LTLHW	1,88 %	2,56 %	3,18 %	1,52 %
MDF	3,24 %	4,56 %	5,34 %	2,41 %
MDF panel	2,79 %	4,33 %	4,37 %	1,82 %
Particleboard	1,54 %	2,54 %	3,23 %	1,97 %
Pine EGB	1,57 %	2,49 %	2,88 %	1,54 %

Sample	Width Swelling from abs. dry (%)			Swelling (SFS 13647)
	RH 35%	RH 65%	RH 75%	Width
Beech EGB	1,57 %	2,46 %	3,00 %	1,68 %
Birch EGB	1,88 %	2,79 %	3,53 %	1,93 %
Kymppi panel	0,30 %	0,39 %	0,47 %	0,21 %
LTL	1,28 %	1,91 %	2,39 %	1,31 %
LTLHW	1,02 %	1,49 %	1,83 %	0,96 %
MDF	0,17 %	0,29 %	0,32 %	0,18 %
MDF panel	0,19 %	0,30 %	0,33 %	0,17 %
Particleboard	0,31 %	0,42 %	0,48 %	0,20 %
Pine EGB	1,40 %	2,08 %	2,50 %	1,30 %

Bending strength perpendicular to the grain

Sample	Thickness (mm)	F_{mean} (N/mm²)	SD (N/mm²)	F_{05} (N/mm²)
Beech EGB	30	9,82	1,96	6,38
Birch EGB	22	6,94	1,33	4,60
LTL	12	4,10	0,89	2,53
LTL HW	10	5,09	0,76	3,75
Pine EGB	18	3,76	1,40	1,29

Bending strength parallel to the grain

Sample	Thickness (mm)	F_{mean} (N/mm²)	SD (N/mm²)	F_{05} (N/mm²)
Beech EGB	30	56,03	14,82	29,94
LTL	30	62,95	8,57	47,87
LTL	20	70,49	8,14	56,17
LTL HW	10	78,55	16,31	49,85
Pine EGB	18	75,31	11,20	55,60

Modulus of elasticity perpendicular to the grain

Sample	Thickness (mm)	MOE_{mean} (N/mm²)	SD (N/mm²)	MOE_{05} (N/mm²)
Beech EGB	30	1,01	0,12	0,81
Birch EGB	22	0,48	0,05	0,39
LTL	12	0,47	0,09	0,31
LTL HW	10	0,38	0,12	0,16
Pine EGB	18	0,26	0,07	0,13

Modulus of elasticity parallel to the grain

Sample	Thickness (mm)	MOE_{mean} (N/mm²)	SD (N/mm²)	MOE_{05} (N/mm²)
Beech EGB	30	12,45	0,87	10,93
LTL	20	10,84	1,08	8,93
LTL	30	10,66	0,88	9,11
LTL HW	30	9,05	1,43	6,53
LTL HW	10	10,73	2,33	6,63
Pine EGB	18	10,29	2,18	6,46